

THE GEOLOGY OF THE NEW HEBRIDES.

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(Plates xiv.-xxix.).

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PREFACE.

The following paper on the geology of the New Hebrides, with which are incorporated the Banks and Torres Groups, is the result of six months' field work carried out under the auspices of Capt. E. G. Rason, R.N., during the winter months of 1903.

In an introductory note read before the Australian Association for the Advancement of Science,* both Mr. W. T. Quaife (biologist to the expedition) and myself have already acknowledged our indebtedness to the various Presbyterian Missionaries in the Group for their ever ready hospitality, and especially to the Rev. F. Bowie, M.A., of Tangoa, and Rev. Dr. McDonald, of Sema, by whose assistance districts otherwise inaccessible were brought within our sphere of operations.

Since our return, by the co-operation of Professor T. W. E. David, F.R.S., the elaboration of the collections has been pushed

* Report of the Tenth Meeting, Dunedin, 1904 [1905].



on with as rapidly as circumstances permitted, and is now presented in as condensed a form as is consistent with not losing sight of such details as may throw light on the main issues of geological research in these islands.

The work of describing the foraminifera has been kindly undertaken by the National Museum of Melbourne, and Mr. F. Chapman, A.L.S., F.R.M.S., has already published one paper† on the oldest fossiliferous horizon in the Group, and has at present under examination, as time permits, a collection of foraminiferous material ranging from Miocene to recent beach sands.

The examination of the mollusca and corals, etc., was undertaken by the Australian Museum of Sydney, and the results of much careful work by Mr. C. Hedley, F.L.S., Conchologist, and Mr. T. Whitelegge, Zoologist, appear arranged in tabulated order in the Appendix. The frequent references to genera of fossil forms found in the beds described, which occur scattered through the text, are all drawn from the work of Messrs. Hedley, Whitelegge and Chapman.

INTRODUCTION.

Although the existence of the New Hebrides has been known to Europeans for 300 years past, dating from the landing of Quiros in 1606 at the mouth of the Jordan River, yet on account of the extreme hostility of the natives, and the prevalence in many parts of malaria of an acute type, this group long remained a *Terra Incognita*; only comparatively recently, since the establishment of the Missions, has a proper knowledge of the geography and natural features been obtained. Geological knowledge of these islands still remained very limited, and with the exception of four or five short papers on the subject, is practically all that can be gleaned from vague reports of vessels cruising in the vicinity, and from casual observations appearing in works of resident missionaries. Several of these notices being very much in error somewhat complicated our work at the outset.

† Proc. Linn. Soc. N. S. Wales, 1905, p.261.

It may be said, therefore, that when we commenced work in the Group previous knowledge of their geological features was not only very partial, but also to some extent unreliable. As our work progressed, however, the evidence (geological and biological) we were able to collect demonstrates the great interest that attaches to the Group as an important factor in elucidating the past history of, at any rate, this portion of the Pacific, and should be of service in settling that much debated subject—the history of coral reefs.

GEOGRAPHICAL FEATURES.

Omitting the SANTA CRUZ ISLANDS, often geographically considered a continuation of the main NEW HEBRIDES GROUP, the belt of islands under consideration stretches for a length of 550 miles in a N.N.W. direction, between Aneityum $169^{\circ} 51'$ E. long., $20^{\circ} 15'$ S. lat. and North Island of the Torres Group $165^{\circ} 40'$ E. long., $13^{\circ} 10'$ S. lat.

HUNTER ISLAND, an active volcano 180 miles to the S.W. by S. of Aneityum, and MATTHEW ISLAND in the same direction, but 30 miles nearer, are to be considered as representing geologically a southerly continuation of the belt.

In relation to neighbouring islands, a reference to the map will show the New Hebrides Group to lie more or less centrally placed, with New Caledonia to the S.W. distant about 190 miles; Viti Levu of the Fiji Group about 400 miles to the east, and San Cristoval of the Solomon Islands about 300 miles to the north-west.

Amongst the islands of the NEW HEBRIDES proper (Plate xxvii.) there are twelve larger islands varying in size from Espiritu Santo with an area of approximately 1500 sq. miles, to Aneityum with an area of approximately 40 sq. miles; of smaller islands there are about 18, averaging a little over 5 sq. miles; in addition there are innumerable small flat coral islands to be considered only as portions of the larger islands around which they are distributed. The archipelago preserves a general N.N.W. direction, along which the factors are arranged

either in single file as is the case in the south, or two and three abreast as in the north (see appended map, Plate xxvii.) The larger islands are high (highest point 5520 ft.), and show extensive exposures of volcanic rocks underlying areas of raised coral terraces, which latter reach in some cases an elevation of quite 2000 ft. The smaller islands are often wholly volcanic; in others raised coral reef-material predominates, and may even completely hide from view the more solid rocks below.

The BANKS ISLANDS, which are really a northerly extension of the eastern arm of the New Hebrides, are almost solely volcanic in origin, reef débris taking relatively only a very small share in their formation; as a result they are high and rugged. Vanua Lava and Gaua are the largest islands, with areas each about 85 sq. miles; ten other smaller islands complete the group and bring the total area up to about 193 sq. miles.

Further to the north-west lies the TORRES GROUP of six small islands with a total area of only about 30 sq. miles. They are composed wholly of raised coral with underlying detrital foundation beds, and rise up in terrace-formation to a maximum height of 1230 ft.

The prevailing wind is a south-easterly trade, though light north-westerlies are not uncommon at certain seasons of the year. Hurricanes are to be expected any time between the latter end of November and the end of February, and are often accountable for much destruction of property.

There are several active volcanoes in the Group, and it is to such agencies that the whole land-surface probably owes its origin. Earthquakes are of frequent occurrence, and are sometimes alarmingly severe; these have occasionally been followed by tidal waves.

PART I.—SEC. I. SYSTEMATIC GEOLOGY.

This section deals with each of the islands separately, and contains all available accurate geological information relating thereto. The limited time at our disposal necessitated very short calls at the various islands excepting Efaté and Santo; indeed,

many had to be passed by with no further examination than could be prosecuted from the deck of the vessel. A detailed report of observations made on the island of Efate and in South-West Santo appears in a later part of this paper.

The titles of references when previous observers are quoted will be found in the bibliography (p. 479).

ANEITYUM is the southernmost island of the New Hebrides proper; it is almost circular in outline, with a diameter of about 7 miles and an area approximately 40 sq.miles.

Our stay at Anelgauhat was so limited that it was possible only to make a geological examination for some two miles inland. A well developed fringing reef completely encircles the island at a distance of about $\frac{1}{4}$ mile from the shore, affording one of the the best examples of growing coral reef-formation to be found in the Group. Beach sand rock is well developed along most parts of the coast visited, giving place above high-water mark to a blown sand rock composed of the finer beach sand material which has been piled up to a height of 10 ft. or so by the trade wind, and there become loosely connected, forming a porous limestone containing a large proportion of mineral fragments; this rock is well shown in a cutting just behind Wilson's store.

Inland from the Mission Station is an area of low-lying ground about half a mile in diameter, evidently once a shallow lagoon, but since reclaimed by the deposition of large quantities of volcanic boulders and other finer material brought down by a small river which empties into the sea a little to the south. Beyond this depressed area the land gradually rises to the flanks of the central range of hills, which attain a maximum height of 2788 ft. The rocks of this region are all eruptive, either dark greenish-grey or light grey olivine basalt porphyrites (1, 2); the latter variety outcrops some distance inland, and is relatively less abundant than the former.

It is possible that remains of old coral reefs may exist at higher altitudes, as is the case in most of the other islands; the contour of the hills, however, does not suggest such to be the case, nor were any boulders of coral seen in the river bed.

When making a call on the northern coast of the island a very strongly developed volcanic agglomerate could be seen forming some low cliffs close by the shore. What, in the distance, appeared to be a similar agglomerate forms a small knob* just to the south of the Mission Station at Anelgauhah.

From what we have been able to ascertain, therefore, Aneityum represents the remains of an ancient volcano of the same age probably as Mau and others further to the north. The northern boundary of the old crater ring appears to be represented by the existing chain of hills; the southern portions do not appear, due to denudation and other causes.

The absence of raised coral reefs demonstrates the fact that regular upheaval, such as is strongly evidenced in the more northerly islands, has not visited this region to the same extent; the conditions being probably that of stable equilibrium or very slow subsidence allowing of the silting up of old lagoons and the formation of a comparatively wide 100 fathom belt.

1. Olivine Basalt Porphyrite outcrops a few hundred yards behind Wilson's store.

Macroscopic Characters.—A compact dark greenish-grey-coloured rock, with porphyritic individuals of pyroxene and olivine standing out conspicuously in a dark base of finer texture. Steam holes are developed to a slight extent only.

Microscopic Characters.—A holocrystalline porphyritic rock. The porphyritic *felspar* individuals are even-sized and rectangular, about 0.6×0.4 mm.; they contain numerous regularly included fragments of magnetite and black glass, and exhibit very perfect polysynthetic twinning after the albite law with an extinction angle referring them to the more basic labradorites. Large porphyritic *pyroxenes* 0.5 cm. diameter represent about 10 % of the rock, and another 5 % is represented by idiomorphic crystals of a pinkish *olivine* 0.8 mm. diameter. The *base*, which is present to the extent of about 15 % of the rock, is

* Since returning we have heard that M. Pelatan had described the rocks of this hill as being similar to New Caledonian serpentines. The source of the information, however, cannot be located.

microcrystalline granular consisting of felspar, greenish-yellow pyroxene and magnetite; it appears as a cementing material between the coarser individuals.

2. Olivine Basalt Porphyrite outcrops at the timber-shoot about 1 mile inland.

Macroscopic Characters.—A light grey-coloured rock in which large pyroxenes and clear felspars appear in a microcrystalline base.

Microscopic Characters.—The rock is seen to be composed of two distinct factors—porphyritic constituents of idiomorphic felspar, pyroxene and olivine individuals to the extent of about 50 % of the rock scattered through a typical pilotaxitic base.

Of the porphyritic constituents the *felspars*, which represent about 25 % of the rock, are large clear crystals, often 7 mm. in length, with extinction angle corresponding to basic labradorite. Another 15 % is represented by *pyroxene* crystals, more or less granular, and averaging 2 mm. diameter; they are of a very light lemon-yellow colour, only faintly pleochroic, and are free from inclusions. Large pinkish *olivines*, about 1 mm. diameter, compose another 8 %, and magnetite grains, 0.5 mm. diameter, another 2 %.

The microcrystalline pilotaxitic *groundmass* of the rock is a meshwork of lath-shaped plagioclase crystals 0.1 to 0.2 mm. in length, with interstices occupied by tiny light greenish-yellow granular pyroxenes and magnetic grains.

Both this rock, and the one described preceding it, have certain of the characters of a dolerite, but are in the main more nearly related to the basalts. They differ from each other not in magma composition, only in relative development and size of the mineral constituents. The darker colour of the first-described type is attributable to the darker appearance of the felspars, due to very numerous inclusions.

TANNA has always attracted much attention from travellers on account of its containing the active volcano of Yasowa.*

* For details see Section 2 (p. 429).

The island is roughly 18 miles long by 10 miles broad, with an area approximately 150 sq. miles. The general direction of the land-surface agrees with that of the central range of hills, and trends to the N.N.W. and S.S.E. The Admiralty chart indicates the maximum height attained as about 3500 ft.

As we were not able to land on this interesting island we quote from reports by the Rev. W. Gray and others, who state that it is composed mainly of volcanic material such as scoria and agglomerate, but that at the north end the soil seems to be derived from sedimentary rocks. Raised coral reefs are stated to occur along part of the east coast, round the north end, and down the west coast, attaining a maximum elevation in the latter locality where they appear at heights of over 100 ft.

Professor A. Liversidge has recorded the analyses of three samples of Tanna lava.* These specimens appear to have been chocolate-coloured to black glassy lavas, for the most part highly vesicular to a degree approaching that of pumice, carrying porphyritic glassy crystals of felspar.

A specimen of a similar lava from Tanna, preserved in the Sydney University Geological Museum, contains porphyritic albite crystals (R.I. 1535); the lava is therefore an andesite.

ANIWA is a small island about 4 miles long by 2 miles wide, situated 12 miles E.N.E. of Tanna.

The Rev. W. Gray has reported raised coral limestone from this island, and as it attains a height of only 140 ft., it is probable that the whole of the land above sea-level is built up of raised reef-material.

The same author has reported native traditions to the effect that a volcano previously existed on the island, and that it was once connected up to the south end of Tanna by a land-bridge. If such be true it would partially reconstruct what might once have been a huge crater ring, the island of Tanna representing the western side only. To settle this point it would be interesting to run a line of soundings to the eastward of Tanna over this submerged bank, if such exists at all.

* Journ. Proc. R. Soc. N. S. Wales, xx. 1886, 236-237 [1887].

FUTUNA is a small island $2\frac{1}{2}$ miles in diameter, situated about 36 miles due east of Tanna.

It appears to be practically wholly volcanic, rising abruptly from the sea to a height of 1930 ft. As it is directly in a line with the earlier eruptive centres, it may be composed of andesite lavas.

ERROMANGA is larger than any of the preceding islands. The dimensions are approximately 30 miles by 20 miles, with an area of 330 sq. miles. It is rugged and mountainous; the highest peak is reported to be about 2750 ft. high.

From the ship, the island appeared to be composed for the most part of lavas and volcanic agglomerates; at lower levels, however, a well-developed terrace-formation of raised coral reefs was seen to predominate. The Rev. W. Gray reports having counted six or seven of these terraces up to a height of 800 ft. Mr. Morrison has noted coral at a height of over 400 ft. at Dillon's Bay, and mentions also the existence of tablelands at an elevation of 1000 ft. as a dominant feature; this suggests a positive movement of the land of 1000 ft. or more. To the east of Port Narevin, some five miles distant, is a high rocky islet hardly more than one mile in diameter; it appears to consist entirely of volcanic rocks.

EFATE is considered by some writers to be the southernmost island of a northern subdivision of the Group, as not only is it the junction-point of the two northern arms, but it is separated by a comparatively wide gap of 63 miles from Erromanga, the northernmost island of the southern subdivision.

It is necessary here only to outline the main features as the island is dealt with in detail in Part ii. (p. 435).

The dimensions are approximately 22 miles by 18 miles, with an area of 300 sq. miles. Of the two very fine harbours, Port Vila* and Havannah Harbour, the former has been chosen as the main shipping station and central port of call for vessels trading in the Group. The mountain system is arranged with a main

* The native name is Fila; the general use of the corruption Vila is due to its adoption by trading companies.

axis in a more or less east and west direction, from which several lesser ridges branch off to the south; the razorbacks are highest at the north-east corner of the island, culminating in Mt. Macdonald, 2203 ft.

Briefly summarised, the geological features are,—a base of andesite pumice tuff overlaid by thick beds of submarine tuff, varying in texture from coarse to much finer-grained types, some of which cannot be distinguished from Fiji Soapstone. Later basic eruptions have affected the N.E. corner of the island, producing thick beds of agglomerate. Superimposed on this foundation and arranged in terrace-formation to a height of quite 2000 ft., is a thin veneer of coral reef-material, which, from its extensive lateral development, has given rise to the popular notion that Efate is entirely composed of coral limestone.

The small islands of MAU, NGUNA, and PELE are practically wholly volcanic, resulting from a continuation of the agglomerate, forming basic eruptions of the mainland. MOSO, LELEPPA, and ERRADAKA are built up of coral limestone on a foundation of fine submarine tuffs.

MATASO is a small island lying 10 miles N.N.E. of Nguna, and has been described by Lieut. Frederick as consisting of two distinct hills joined by a low beach of sand and coral. The higher of the two hills is a remarkable peak 1669 ft. in height, and only 1870 yds. long by 1000 yds. broad. The lower hill is 485 ft. high. The whole island is, he says, of volcanic origin; a narrow fringing reef is, however, growing at present on either side of the island (Plate xvi., fig.1).

MONUMENT ROCK.—A precipitous pyramid rising vertically from the sea 1 mile E. of Mataso, is described by the same authority as being 422 ft. high and 130 yds. in diameter at the base; although a landing could not be effected for the purpose of collecting specimens, yet he states it is evidently wholly composed of volcanic rock.

MAKURA is situated 6 miles north of Mataso, and is just one mile in length. It is of volcanic origin, rising up in the form of

a peak 1000 ft. in height. A dolerite collected from this island has been described by Mr. J. J. H. Teall.

MAI lies four miles N.E. of Makura, and has approximately the following dimensions: length $5\frac{1}{2}$ miles, breadth $2\frac{1}{2}$ miles, and an area of $7\frac{1}{2}$ sq. miles. Capt. Cook named it Three Hills Island on account of a well marked topographical feature; the highest of the peaks reaches an elevation of 2171 ft. Lieut. Frederick has reported the island to be of volcanic origin.

THE COOK REEF is an example of a coral atoll in its earlier stages of development. As we were not able to visit this interesting spot, we can only quote from the Admiralty surveys. Its external dimensions are roughly 2 miles by $1\frac{1}{4}$ miles. The lagoon is completely enclosed by a belt of growing coral reefs which are exposed at low tide in patches for a width averaging about a quarter of a mile. The absence of permanently dry land is no doubt owing to its youth, and it is probable that in a comparatively short time to come patches of land will make their appearance, due to the piling up of broken off fragments of reef-material. The future history of the atoll is entirely dependent on local movements of the earth's crust, in so far as if the upheaval, so generally evidenced throughout the Group, be continued, the Cook reef will some day be presented to us as another Mango; if, on the other hand, a slow subsidence makes its appearance in the Group, then by upgrowth and outgrowth a typical coral atoll of the Funafuti type might result.

THE SHEPHERD ISLANDS are a group of seven small islands, together with numerous islets, reefs and banks, extending S.E. of Epi for a distance of 14 miles. Lieutenant Frederick describes the Shepherd Islands as being all of recent volcanic origin. He is of opinion that they once formed part of a huge crater. As substantiating this argument, he refers to a native legend to the effect that about 300 years ago the land broke up in this vicinity and remnants only were left, forming the present system of isolated islands. However far this may be true, there certainly

appears to be evidence of the existence of an old crater between Tongoa and Epi.

TONGOA, the largest of the three islands, is subcircular in outline, with an area of about 10 sq.miles. Abutting on to the sea-cliffs at the north side is a district about twenty acres in extent where the ground is heated to almost 212° F.; just three miles N.W. of this point a submarine eruption took place in 1897. A specimen of rock taken from the vicinity of the hot ground has been described by Mr. J. J. H. Teall as an augite andesite. Another specimen of rock from the summit of the highest point on the island—1674 ft.—examined by the same authority, proved to be basalt.

EPI is of special interest, as it was briefly visited by the 'Challenger' Expedition; little examination of the island was, however, then effected, as the scientists during the few hours spent on shore did not venture to wander out of sight of the beach. Dr. J. Murray recorded the existence of raised coral 5 ft. above sea-level, and reported having found water-worn fragments of coral limestone in a creek bed hard by. It is the tracing of these pebbles back to their position *in situ* that Moseley refers to when he says that on this occasion Dr. Murray came so near making an important discovery.

Our examination of the island was limited to short visits at The Foreland and at Diamond Bay.

The dimensions of the island are approximately 22 miles by 9 miles, with an area of 100 sq.miles. The hills run in a W. to N.W. direction, and attain a maximum elevation of 2791 ft.

The island appears to be wholly composed of volcanic material overlaid by raised coral limestone. Along the west coast cinder beds and soft volcanic tuffs are extensively developed, as also are the overlying limestones. The best section obtained was at The Foreland, (text-fig.1) where a well developed coral limestone, elevated to a height of at least 100 ft., caps thick beds of greyish-coloured foundation-beds composed partly of organic remains and largely of volcanic cinder(1). In the upper portions of these beds

rounded pebbles of pyroxene andesite make their appearance and are specially frequent in the passage beds just below the coral capping.

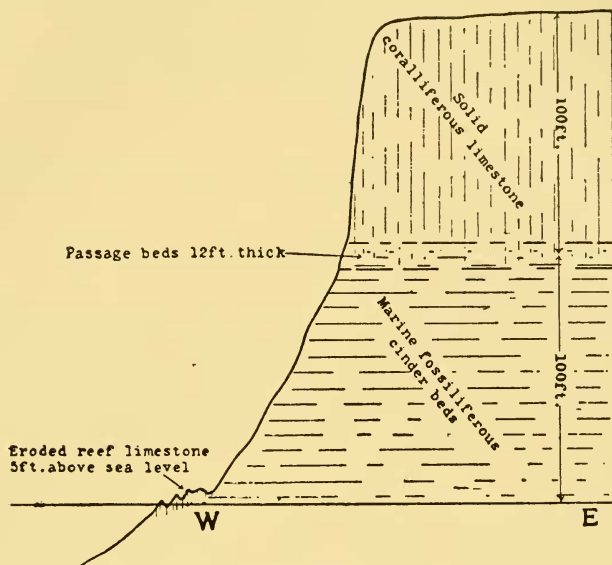
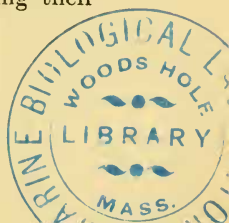


Fig.1. Section of the cliffs at The Foreland, Epi.

1. Fossiliferous Cinder Beds below the raised coral at The Foreland, Epi. The rock is of a medium grey colour, readily friable, and abounds in marine organic remains.

About 50% or more of the material is represented by small fragments of *olivine*, *felspar*, *pyroxene* and *magnetite*, and very numerous dark-coloured fragments, sometimes up to 2 cm. diam., of more or less glassy vesicular *volcanic cinder*.

The remainder of the rock is represented by shells and skeletons of various marine organisms, often of large dimensions. Isolated corals and rounded pebbles of pyroxene andesite are scattered through it indiscriminately, but become more abundant just below the coral capping, where 12 ft. of passage beds are indicated in the section. These passage beds, by gradually losing their



cindery appearance and acquiring an increased abundance of corals, pass upwards into a solid coral rock.

The following forms have been identified as occurring in this bed :—

Pelecypoda—3, 6, 7, 9, 11, 12, 13, 23, 26, 27, 30.

Gastropoda—5, 8, 12, 17, 19, 24, 26, 34, 35, 38, 39, 43.

Echinoderms—1, 2, 4.

Corals—8, 15.

In the lower portions of the overlying reef the following fossils were collected :—

Pelecypoda—4.

Corals—10, 14.

PAU UMA is a rugged island situated between Epi and Ambrym. It has a length of 5 miles, breadth 2 miles, and area 9 sq.miles. Running in a N. and S. direction down the centre of the island is a chain of mountains, apparently volcanic, attaining a height of 1825 ft. No reliable data relating to the geology of this island are available.

LOPEVI is a remarkable volcano situated 16 miles S.E. of the crater of Ambrym. It is only 3 miles in diameter at the base, but it towers upwards in a perfect cone to the crater, about a quarter of a mile in diameter, situated at an elevation of 4755 ft. Although not always active, Lopevi has several times since European occupation poured forth lava, which, welling over the crater, has descended from that immense height in brilliant streams down into the sea.

AMBRYM is triangular in general outline, with a greatest length of 21 miles, and an area of 160 sq.miles. The island is a remnant of an immense volcano,* with an extinct crater six miles in diameter; at the present time, however, activity is restricted to minor vents situated in two daughter-cones.† The floor of the

* For further details of volcanic phenomena, see Section 2 (p. 427).

† The term daughter-cone is here used to signify a younger development inside an older crater.

old crater, 2100 ft. above sea-level, is now thickly covered with ash derived from subsequent outbursts, which feature has gained for it the name of "great ash plain." Bounding this plain is a broken line of peaks averaging almost 3000 ft. in height. Towards the western side the two daughter-cones are overhung by Mt. Benbow, 3720 ft., and Mt. Marum, 4380 ft., which rise high above the old rim; each of these younger craters is about one mile in diameter.

Lieut. Beresford has remarked the fact that these more elevated portions of Ambrym are built up of tuff and cinder beds, whilst outcrops of solid lava are a more prominent feature of lower levels.

The remains of several parasitic craters can be seen when steaming round the island; a radical section through one of these is beautifully exhibited on the sea-cliffs at Dip Point, where a perfect cone several hundred feet in height, built up of alternating layers of coarser and finer ejectamenta, ideally portrays the interior structure of a volcanic cone.

MALEKULA is the second largest island of the Group, with a length of 50 miles, greatest breadth of 20 miles, and area about 450 sq. miles. The general topographical features of this island are in striking contrast with the coral-terraced volcanic slopes of the more southerly islands just considered. The whole aspect is that of an older land-mass; the dome-shaped mountains of no very great height (highest point Mt. Penot, 2925 ft.) with flat land intervening indicate a considerable lapse of time since first the land was raised above the sea and exposed to a tropical denudation which since has planed down and laid bare the cores of then existing lofty peaks and usurped the strippings to even up the valleys, leaving a permanent record of its extensiveness in thick beds of alluvium exposed in present river cuttings.

On account of the prohibitive savagery of the natives, explorations in this island are necessarily limited; we were, however, able to examine the east coast from Port Stanley to the northward, making several excursions well into the interior.

Numerous small flat coral islands form an almost continuous chain extending along the northern part of the east coast, distant

usually about one mile from the mainland. These islands seldom exceed 30 ft. in elevation, and are formed of decomposed basic tuff covered over by a thin veneer of coral limestone. A thriving fringing reef is rapidly extending the eastern shores, but does not appear to the same extent on the landward side.

Our first excursion on the mainland was to the hills above Port Stanley, where recent raised coral limestone (87) was observed to give out shortly above sea-level, to be succeeded above by a decidedly more ancient-looking dense, white limestone;* this latter was traced up for a height of 500 ft., after which several outcrops of decomposed tuffs were noted.

An excursion from the island of Rano to the mainland at Pinalum Point and inland about four miles was of little interest, as the track lay on fairly level ground, the only outcrop noticed, besides occasional patches of hard compact yellowish fragmentary limestone, was that of a basic tuff(1) underlying the limestone, and though only occurring very rarely in recognisable outcrops, is probably extensively developed as detected by the slipperiness of the path for the whole distance. Several pebbles collected from a creek-bed at the farthest point reached proved to be Miocene limestones and hornblende andesites. Large slabs of Miocene limestone (91) are used as seats in an amil several miles inland; these had, according to the natives, been transported some distance.

With our camp on the small island of Atchin we made two excursions to the mainland.

On the first of these, after landing on the shore directly opposite our camp, we followed a track leading due west, and finally, after about a two miles' tramp, arrived at the upper reaches of a river which enters the sea just to the north of Atchin. A flat shore-belt elevated only a few feet above sea-level occupied the first half mile or so, after which a gradual rise

* According to Mr. Chapman, the absence of *Lepidocyclina* indicates a Post-Miocene age for this material, though no doubt the disparity is not great, as evidenced by the presence of abundant forms found associated in the local Miocene.

of about* 150 ft. brought us to the top of a recent raised coral reef in which *Orbicella* sp. was recognised. Just beyond this point a steep descent of 50 ft. brought us to the river-bed, where a collection of rolled pebbles was made. Several of these specimens proved to be pyroxene andesites, one a uraltite porphyry,† whilst two others appear to belong to the same parent-type as the latter, but differ in degree of metamorphism. The river at this spot cuts through quite 50 ft. of drift material, which had probably been laid down on an extensive scale at a time previous to the uplift indicated by the neighbouring raised reef. On arriving at the beach, we examined the deposits of magnetite iron sand(2) extensively developed along this coast.

Our second excursion from Atchin was directed to the village of Laleppe‡ and resulted in several interesting discoveries. Our route lay direct to Bartaleppe, thence by a détour after mounting a

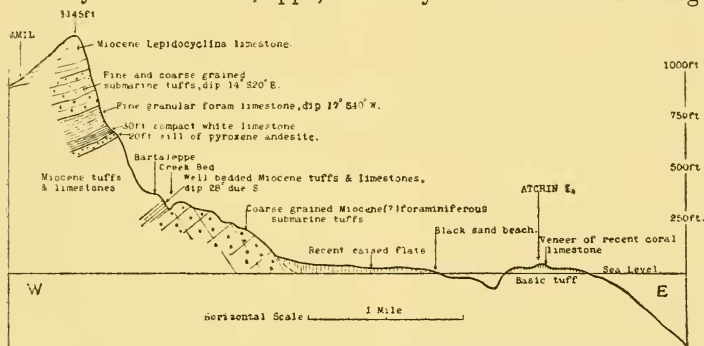


Fig. 2. Sketch section from Atchin to Laleppe, North Malekula.

sharp spur we arrived at Laleppe. Turning to the left and partly doubling back we continued to rise to the point 1145 ft. high indicated on the chart. A rapid descent brought us to Bartaleppe again. In the woodcut (text-fig.2) a slightly

* Our aneroid got out of gear, and we were obliged for several months to calculate the heights as best we could. Later on, however, Professor David forwarded an excellent instrument, lent by Mr. G. H. Knibbs, F.R.A.S., by which, with the aid of a vernier, readings could be readily taken to one foot.

† For description, refer to Part ii., Section 3, § 9.

‡ Such names may be spelt either Laleppe or Lalembé, as it appears on the Admiralty chart.

generalised section is given, whereby the outcrops on both tracks to Laleppe are incorporated in the same section. The trip took us a whole day's hard walking, and a considerable number of miles must have been covered. Nevertheless, when plotted in a direct line, it pans out as three miles only.

The first mile inland passes over low flat country of the nature of recent raised reef and shore debris; beyond it rises gently for $\frac{3}{4}$ mile to the village of Bartaleppe, elevated probably 400 ft. above sea-level. Outcrops along this part of the track show it to be underlaid by coarse-grained foraminiferal tuffs (99) of doubtful age, either Miocene or newer. About 100 yds. before arriving at Bartaleppe a narrow creek is crossed, in which well-bedded Miocene tuffs and limestones (3) (106)* dipping 28° due S. are encountered. After leaving Bartaleppe further outcrops of Miocene (109) tuff beds appear for a height of several hundred feet. Then comes a 20 ft. sill of augite andesite intersecting the limestones along the bedding planes; the sill is overlaid by a 30 ft. bed of a hard white limestone; above this again, is quite 100 ft. of a granular foraminiferal limestone (4) (102) of Miocene age, much resembling sandstone, and dipping 17° S., 40° W.

We had now arrived at Laleppe; continuing to ascend we passed over thick beds of coarse and fine mineral tuffs(5) capped by foraminiferal limestones, the *Lepidocyclina*-*Lithothamnion* limestone (6) (105) outcropping at the amil. Limestones (108) continued to outcrop to the top of the hill, 1145 ft. On the way down to Bartaleppe fine-grained grey submarine tuffs (7) (107) with abundant *Globigerina* and pellets of pumice were met with below the white limestone zone, dipping 14° S., 20° E.

Note that the three dip readings taken in the Miocene series differ very widely; this points to great local earth-movements, contemporaneous with or subsequent to their deposition.

Summarising the preceding observations, we notice as a conspicuous feature of the geology of Malekula in the districts

* The small figure refers to accompanying description; numbers in large they are those appearing on the specimens, and are inserted for reference in connection with Mr. Chapman's work.

examined, the meagre development of recent raised reefs, and their complete absence at elevations exceeding 150 ft. This is more to be wondered at when it is remembered that it lies midway between Efaté and Santo, both regions of extensive recent upheaval.

Referring to the Admiralty chart it will be noticed that elevated plateaux and white cliffs are a dominant feature of the north-west coast; these cliffs may possibly be composed of Miocene limestones, but the contour strongly suggests a more recent age. If this latter be the case, then the non-appearance of recent coral at similar elevations on the parts of the coast examined may be due to proximity to the volcano of Ambrym.*

The land appears to be built up, for the most part, of a great thickness of Miocene submarine tuffs and foraminiferous limestones, intruded by andesite sills and dykes,

In all probability dry land has existed since Miocene or early Pliocene times; and although little subsequent elevation is evidenced, yet, situated as it is, in the midst of abundant proof of extensive recent upheaval, there can be little doubt but that it has weathered out a succession of oscillations resulting finally in a slight positive movement.

1. A decomposed fine-grained *basic ash* derived, no doubt, from the volcano of Ambrym, which is situated only 38 miles to windward. Small fragments of decomposed pyroxene appear in a very fine-grained yellowish dust-like base, which when dried is light and very absorbent. This rock is found also underlying a scanty coral capping and composing the main body of the small islands of Rano and Atchin; in all probability obtains an extensive development on this coast of Malekula.

2. *Black sand* is a marked feature of the sea-shores throughout a large part of the Group, and in such neighbourhoods is also found to a less extent in the river-beds.

* Referable to two causes—First, an inward dip towards the volcano of Ambrym is to be expected and might be sufficient to account for a much greater elevation on the west than on the east coast of Malekula. A second explanation, though much more limited in application, might be found in Lieut. Frederick's observation that coral polyps do not live near the active volcanic islands, *e.g.*, Tongoa.

At Black Sand Bay on the east coast of Malekula, and for some distance to the northward, very large quantities are to be found, highly concentrated within the wash of the waves and decreasing in richness very rapidly towards the land, where it blends with the soil. It consists very largely of magnetite, in addition to which is a varying quantity of pyroxene and felspar; the sand is derived from the decomposition of ash-beds and lavas. Usually on digging down into it alternating bands of a black and of a yellowish-green hue a few inches in thickness can be detected, due to the varying concentration of the magnetite constituent. The grain-size usually averages 0.2 mm., but exceeds this in several localities, as, for example, near the Roman Catholic Mission on the north coast of Aoba, where it averages 2 mm. diam.

3. Well bedded *Miocene tuffs* and *limestones* appearing in the stream a few hundred yards below Bartaleppe. The coarser-grained grey types are largely composed of subangular fragments of pre-existing calcareous rocks averaging 0.5 mm. diam., and fine mineral grains; the binding material is a calcareous cement. Other fine-grained grey types, often much stained along the joints by manganese, are very largely built up of *Globigerina* tests.

4. *Granular foraminiferal limestone* resembling a sandstone in general appearance and of a greyish colour tinged with brown and black spots. It is composed of a mass of foraminifera (*Miocene*), pieces of black volcanic glass containing lath-shaped felspars, angular fragments of a yellowish calcareous sedimentary rock, and occasional grains of plagioclase, pyroxene and magnetite.

5. *A grey mineral tuff* similar to those of the Wai Bubo in S.W. Santo. The rock is composed of grains of felspar, hornblende, augite, and magnetite, together with numerous fragments of andesite lavas, and much decomposed reddish-stained opaque material resembling palagonite. This rock is, for the most part, barren of organic remains, though the discovery in it of an echinoderm spine served to settle its submarine origin.

This coarse variety gives way in parts to a very fine-grained chocolate-coloured rock recalling some of the shaly tuffs of the Wai Malikoliko, S.W. Santo.

6. *Miocene limestone* in situ at the amil above Laleppe. It is a hard *Lepidocyclina*-*Lithothamnion* limestone containing small fragments of a basic eruptive rock, and of a fine-grained submarine tuff.

7. *Fine-grained grey submarine tuffs* containing abundant *Globigerina*. They are well bedded, finer-grained beds several cms. thick alternating with coarser beds in which tiny pellets of white pumice are visible. This structure strongly resembles that of the soapstones at Largeaux's plantation in Efaté.

Dr. Hinde described three rock-specimens collected by Lieut. Frederick from Malekula :—

(a) From Rocky Point, Sasun Bay, at 3 ft. above sea-level. A brownish compact claystone, containing a few *Globigerina* casts. The matrix was recognised as being composed of very fine volcanic material. This rock tallies with the Miocene submarine tuffs collected by us further north, and also with some of the bands of the Efaté soapstones.

(b) From the same locality at 10 ft. above sea-level. A grey soft granular limestone with nullipores, foraminifera, etc.

(c) From Port Stanley, at an elevation of 550 ft. A white limestone, in which, among other forms, *Lithothamnion* was recorded.

We collected specimens of what must be the same limestone, and find that it is probably to be relegated to some part of the Pliocene.

Professor Liversidge analysed a rock collected by Commodore Goodenough from the shore below h.w.m. at Port Sandwich. This appears to be a fine tuff, but details are not sufficiently definite to warrant quotation.

SANTO is the largest island in the New Hebrides, and has the following approximate dimensions :—Length, 75 miles; breadth, 30 miles; and area, 1500 sq.miles.

Extending continuously down the west coast is a high range of mountains attaining a maximum elevation in Losubunu, 5520 ft. (Plate xviii.). These mountains ascend steeply from the sea, rising in a succession of sharp ridges culminating in lofty peaks only four to six miles inland. The eastern flanks are much less precipitous; after descending to 4000 ft., what appears to be a plain of marine erosion, deeply furrowed by short and rapid rivers, is a noticeable feature extending along the range for quite 10 miles, surrounding the peak which rises high above it as a monadnock. Beyond as far as the east coast, a distance of 20 miles, the high lands of the interior continue to maintain their plateau-like aspect, though with decrease in altitude, and occasional interruption by minor features (Plate xxi.) On the east coast, where the plateau was ascertained to be built of recent raised coral and reef débris, it is only 500 or 600 ft. in height, and is noticeably more elevated in the north than in the south. This agrees with the evidence obtained in Malekula indicating a general dip to the east in conjunction with a less noticeable sag in towards the nearest volcanoes.

On the south and east numerous small islands line the coast, and are found to maintain the same general geological features with the adjacent mainland. Along the west coast recent raised reef-material is little represented further north than C. Ukuani (Plate xx.). Beyond that point older rocks, amongst which is a highly-tilted Miocene series similar to that already described from Malekula, outcrop at sea-level (Plate xvii.), and rising steeply appear to compose, with related andesites, the whole mass of the neighbouring elevated ridges.

Above the Miocene, and developed most strongly on the eastern side of the island, come soft submarine tuffs of the Fiji soapstone type, capped above by a variable thickness of recent raised coral attaining a maximum observed elevation of about 1000 ft.

It is to be noted that the fine-grained grey gneiss reported by M. Levat as being eminently characteristic amongst the rocks of West Santo and West Malekula, was not met with by us; the

oldest rocks encountered being volcanic agglomerates underlying the fossiliferous Miocene series.

AOBA occupies a position midway between the eastern and western wings of the Group. It is oval-shaped with the following approximate dimensions:—Length, 25 miles; breadth, 8 miles; area, 105 sq.miles.

There is a little low-lying land, undulating in character, at either extremity of the island; for the rest it rises steeply to a height of 4000 ft., at which elevation the natives report the existence of a shallow lake, no doubt occupying the position of a former crater.

The island, so far as ascertained in our short visit, is entirely volcanic, and cannot long have been extinct. Specimens collected of the volcanic rocks were tuffs, agglomerates, and vesicular and porphyritic basic lavas, conspicuous amongst which were olivine basalts bearing olivines one-third of an inch in diameter, and porphyritic pyroxene olivine basalts.

The fragmentary types of rocks proved to be much more abundant than solid lavas; the former being specially abundant at the eastern and western extremities of the island.

A very fine example of bedded tuffaceous ash-beds is to be noted at the north end of Bice Roads, where they appear well bedded, dipping 12° S., 45° W., and overlies solid lava. The finer material constituting these beds is of the nature of pulverised volcanic rock; distributed through this base, in roughly parallel bands, are pebbles and boulders, up to 2 ft. in diameter, of various types of basalt. No raised coral was observed on the island, though growing reefs fringe the south-east shore.

ARAGH ARAGH or PENTECOST ISLAND extends northward of Ambrym, forming part of the eastern wing of the Group, which continues through the Island of Aurora to the Banks Group.

The island is long and narrow, with a greatest length of 35 miles, breadth 6 miles, and approximate area of 125 sq.miles. A high ridge attaining a maximum elevation of 2500 ft. runs in a north and south direction, forming a backbone to the island. Its rugged aspect bears the semblance of a volcanic island.

AURORA or MAEWO ISLAND is, like Aragh Aragh, long, narrow, and mountainous. It is, however, more elevated, probably attaining a height of close on 4000 ft.* The dimensions are :—Length, 32 miles; breadth, $3\frac{1}{2}$ miles; and approximate area, 90 sq.miles. It is probably wholly composed of volcanic rocks.

THE BANKS GROUP lies about 50 miles to north of Aurora. With the exception of some of the smallest, the islands are all of volcanic origin, and, as evidenced by the fumaroles of Vanua Lava, are of comparatively recent age.

VANUA LAVA† or the GREAT BANKS ISLAND.—Approximate dimensions are :—Length, 15 miles; breadth, 10 miles; area, 85 sq.miles.

High rugged ranges of mountains run in a general north and south direction, attaining a maximum elevation of 3120 ft. In the north centre hot springs and fumaroles cover a considerable area of ground, giving rise to hot-water creeks which, uniting together, enter the sea at Port Patteson.

The entire island appears to be composed of volcanic rocks, of which porphyritic pyroxene and olivine pyroxene basalts are the most abundant. Other than basic lavas, was one specimen of a pyroxene andesite.

It seems probable that Vanua Lava represents the south-west portion only of a former immense crater, which included also the islands of Mota and Valua. The general distribution of the islands, the soundings, and the dip of the agglomerate and cinder beds, all favour this view.

MOTA is a hat-shaped island 2 miles in diameter. The rim of the hat, so to speak, is a broad shore-flat, in the development of which, coral has no doubt participated; the central peak, 1350 ft. high, appears to be volcanic.

* The Admiralty chart has it marked down as about 2000 ft., but to us it seemed quite as lofty as Aoba.

† M. Levat has reported the occurrence of gneiss and trachyte on Vanua Lava; this we think is entirely a mistake.

VALUA is 6 miles long, and 7 sq. miles in area. Viewed from the vicinity of Mota, we noted sharp outcrops of steeply dipping rocks, forming the central range, with sufficient distinctness as to be almost certain that they represent alternating beds of solid lava and softer tuff.

PAKEA.—A small flat island situated at the southern entrance to Port Patteson, and elevated only a few feet above sea-level, is composed of tuffaceous volcanic material which, near the shore, has been cemented by calcareous organisms into more solid beds.

THE REEF ISLANDS are about five permanently dry patches of small dimensions, scattered along a semicircular coral reef, $5\frac{1}{2}$ miles long, and $1\frac{1}{2}$ miles wide at the broadest part.

In course of time the growing reef will probably complete the ring, supplying a further example of coral atoll-development.

GAUA is approximately 10 miles square. The area, 85 sq. miles, is equal to that of Vanua Lava. Highest point, 2300 ft.

Towards the eastern side, elevated a considerable height above the sea, is an old crater lake two miles in diameter. Good exposures of lavas, alternating with tuff beds, were noted at several points along the sea-cliffs. At Lakona Bay, where a landing was effected, a bed of lava 20 ft. thick was found overlying coarse tuffs. In the same locality several different lava streams were noted within a short distance along the coast which, when traced inland, were found to alter very little in character for a distance of upwards of two miles. The specimens of lava collected were various types of basalts, in most of which appeared phenocrysts of pyroxene and olivine.

UREPARAPARA is oval in shape, $4\frac{1}{2}$ miles by $3\frac{1}{2}$ miles; area about 11 sq. miles. Highest point, 2440 ft. The island is an extinct volcano, possessing a unique harbour in the old crater, which has been invaded by the sea breaking through on the eastern side. Anchored there in Dives Bay, a wonderful view is presented all around in the steep slopes leading up to the crater lip, over 2000 ft. above.

The island is entirely volcanic. Rocks collected on the south-east side of Dives Bay proved to be porphyritic basalts(1) and an interesting type of basic lava(2) possessing an andesitic facies.

MERLAV, 2900 ft., MERIG, 200 ft., VATGANAI, 250 ft., and several minor islets not mentioned, we were not able to visit, but, like the rest, they are no doubt of volcanic origin.

1. Porphyritic Basalt from the south shore of Dives Bay.

Macroscopic Characters.—A compact grey rock homogeneous in appearance.

Microscopic Characters.—A fine-grained basaltic base through which are porphyritically distributed abundant corroded *labradorite* feldspars up to 1 mm. diameter, constituting about 18 % of the rock; occasional porphyritic individuals of a light green *pyroxene* frequently twinned on the (100) face and measured up to 1 mm. diameter; relatively large grains of *magnetite*, up to 0.75 mm. diameter. The *base* consists mainly of tiny lath-shaped feldspars with augite microlites, magnetite dust, and an indistinct glassy residue.

2. Olivine Pyroxene Porphyry from the south shore of Dives Bay, near the Mission Station.

Macroscopic Characters.—A dense dark-coloured rock with gleaming porphyritic pyroxenes and abundant rectangular feldspars.

Microscopic Characters.—Distributed through a more or less glassy base are porphyritic individuals present to the extent of about one-half the rock-mass. The *feldspars* are rectangular, pointing in the direction of flow, and regular in size, averaging 1 mm. $\times$ 3 mm.; they are well zoned, dusty bands being especially characteristic; judging by the extinction angle on the albite twin, its composition must be in the vicinity of $Ab_5 An_4$. From the description these feldspars will be seen to have the facies of those developed in andesite lavas; appearing in so basic a rock as this, they are therefore of special interest. In addition to feldspar individuals, which compose about 25 % of the rock, are large apple-green *pyroxenes* to the extent of 12 %;

smaller *olivines* 5 %, much decomposed and stained red by iron oxide; large *magnetite* grains 3 %. The *base* is largely glassy, but contains particles of plagioclase, augite, olivine, with abundant magnetite dust.

TORRES or VAVA ISLANDS.—The approximate dimensions of the four main islands are: Toga or South Island—3 miles long, area 5 sq.miles, height 896 ft. Lo or Saddle Island— $3\frac{1}{4}$ miles long, area 4 sq.miles, height 390 ft. Tegua or Middle Island—4 miles long, area (with Ovale I.) 7 sq.miles, height 640 ft. Hiu or North Island—7 miles long, area 14 sq.miles, height 1230 ft.

The islands of this chain preserve a W.N.W. trend, and are separated by narrow channels about 2 miles wide; they appear to be a continuation of the western arm of the New Hebrides.

Time did not allow of a detailed examination, and general impressions only can be given.

They appear to be wholly composed of a coralliferous limestone formation rising up in terraces to a maximum elevation of 1230 ft. All the rocks examined were coral limestones, but, no doubt, these are underlaid shortly below by tuffaceous foundation-beds.

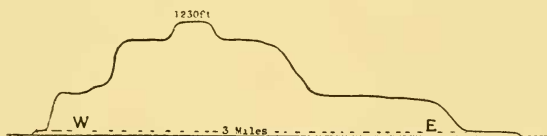


Fig.3. General outline of Hiu, Torres Group; looking from the south.

The woodcut (text-fig.3) was sketched from the deck of H.M.S. 'Archer' while steaming along the south coast of Hiu, and affords a general idea of the topography of the Torres Islands.

SEC. 2. VULCANOLOGY AND SEISMOLOGY.

ACTIVE VOLCANOES.—The volcanoes of the New Hebrides have attracted more attention from visitors than have any of the other physical features, and as a result numerous descriptions are on record.

Included within the region of our explorations are the two permanently active volcanoes of Yasowa and Ambrym. Further

to the south, but still part of the same volcanic zone, are the volcanoes of Hunter I. and Matthew I., the former of which was reported to be in active eruption at the time of our visit; to the northward in the Santa Cruz group is the active volcano of Tinakula.

AMBRYM.—The Island of Ambrym represents the truncated cone of an ancient volcano of gigantic dimensions; now, however, exhibiting only a tithe of its former energy. Distributed around its flanks are numerous parasitic cones, most of which are extinct, though several are known to have been active within recent years (for topographical features refer to Part i., Sec.1).

The most violent of recorded outbursts from this volcano took place in October, 1894, and has been excellently described by Capt. Purey-Cust, at that time Commander of the survey ship H.M.S. 'Dart,' then stationed at Ambrym. With the first shock of the outburst, ash, steam, and smoke from the burning timber which had thickly clothed the slopes almost to the top, rose up in dense cerebriform masses of clouds over Mt. Benbow to a height of 15,000 ft.; streams of lava poured out of fissures in the ground at several points along the slopes of the old cone and rushed down into the sea. Capt. Purey-Cust, anxious to obtain a nearer view, steamed the 'Dart' to within $\frac{1}{4}$ -mile of where one of these flows was making, and describing the sight witnessed, says :—" Presently the head of the stream appeared—a red hot, rapidly moving mass of molten lava, some thirty yards wide, with lumps of clinker tossing about on its surface. In another moment it entered the sea, and then a most wonderful sight was seen, such as none of us as then saw it will probably ever see again as long as we live; a dense pillar of steam rapidly rose straight up to a height afterwards measured by a sextant and found to be 4600 ft. There was no explosion as the lava touched the water, but a few seconds later enormous bubbles of water commenced to rise up to 100 ft. or more, like the explosions of heavy submarine mines, and then burst violently outwards in radiating tongues of water and black masses of, presumably, lava."

Later on with the opening of a second vent a mass of dark-coloured smoke rose up rapidly to a height of 26,000 ft. in ten minutes.*

As soon as matters had calmed down somewhat a party from H.M.S. 'Dart' made a daring trip to the crater of Mt. Benbow, where, leaning over the edge and viewing the swirling lava in several active vents some 1000 ft. below them, they experienced what Capt Purey-Cust has described in the following words:—"Far down in the bowels of the earth could be heard a roaring like a heavy surf beating on the shore. The crackling of the stones as they struck one another in the air was like a constant heavy roll of musketry fire, with occasional reports and echoes back from the walls of the crater, until it sounded as if a general engagement was taking place. The ground where we sat was in a state of constant tremor, with an occasional rather severe shock."

At the time of our visit a wreath of smoke could be seen in the daytime curling upwards from the vicinity of Mt. Benbow; at night a brilliant sight was presented for miles to the southward, where the reflection of a red glare on the smoke and steam clouds overhanging the crater could be seen perceptibly brightening every three or four minutes, only to diminish gradually until the next period.

The volcano of YASOWA on the island of Tanna was first visited by Captain Cook, from whose report it appears to have been more active then than now. Though continuously active, no inconvenience is caused to the inhabitants of the island, except for occasional showers of ash.

Situated on the slope of the main range, about four miles inland from the Mission Station at Port Resolution, it is roughly conical in shape, and surrounded by absolutely barren ground, $\frac{1}{2}$ -mile to 2 miles wide. The most elevated portion of the rim is on the N.W. side, and is about 1300 ft. in height; just below this point at the foot of the cone is a shallow lake.

* These figures are interesting, as they are no doubt highly accurate.

Extensive solfataras exist on the range-side of the cone. The crater is stated by the Rev. W. Gray* to be elliptical in shape with a circumference of quite 1 mile, and a depth of 300 ft. Two main divisions separated by a rocky barrier each contain several active vents, which are continuously throwing out bombs; the accumulation of these ejected fragments appears to have built up an inner ring round the crater, portions of which occasionally slide down into the chasm below, temporarily blocking the vents.

Several sudden uplifts, immediately due possibly to intrusions of lava, but undoubtedly primarily resulting from a continuance of folding movements in the rocks below, have been reported from the vicinity of the crater, resulting in the original safe harbour of Port Resolution, where Capt. Cook anchored in 1774, being rendered almost useless. The first of these recorded happened in 1878, when, after a series of earthquake shocks, the land jumped up a distance of 20 ft., and later another 12 ft. In 1888 severe earthquake shocks and increased activity of Yasowa were again accompanied by an upheaval of the land to a height of at least 30 ft.

DORMANT VOLCANOES.†—LOPEVI is a perfect cone in shape, with a small crater situated at an elevation of 4755 ft. It was reported to be very active in 1863-64, and less so again about 1884.

Parasitic cones on Ambrym break out at intervals, notably one at an elevation of 1190 ft., towards the S.E. end, which is known to have been active in 1888 and again in 1894.

At the north-west end of Tongoa there is permanently hot ground. In 1897 a small island was formed by a submarine volcano between this point and the island of Epi; it has, however, since been reduced to a shoal.

* From a letter addressed to Mr. H. C. Russell, B.A., C.M.G., F.R.S., Government Astronomer, Sydney, then Secretary A.A.A.S. Seismological Committee.

† The Rev. S. Ella, in 1890, when enumerating the volcanoes of the Group, mentions that the island of Pau Uma has one crater. We heard nothing of this when in the Group; it may nevertheless be correct.

At Erromanga, between Traitor's Head and High Rocky Islet, a submarine volcano was reported in 1881.

Vanua Lava,* in the Banks Group, is famous for its boiling springs, which, covering a considerable area, indicate its dormant condition.

EXTINCT VOLCANOES.—As practically all the islands of the New Hebrides represent some part of the wreck from a volcanic eruption, a list of the extinct volcanoes would embrace almost all the Group not already included under the titles of active and dormant. The several mentioned below are therefore only such as are known to still preserve their typical shape.

UREPARAPARA, GAUA, MERLAV, and AOBA all have their craters filled with water. NGUNA, MAU, and PELE are cones of the later basic eruptions of Efaté.

HOT SPRINGS.†—The following have come under observation :—

Boiling springs in an elevated region close to the easterly slope of Mt. Suretamati on Vanua Lava.

On the island of Tanna, in the vicinity of the crater of Yasowa, boiling springs are numerous.

Hot springs on the island of Ambrym at Bat-in, and again on the N.W. coast south of Rannon Anchorage. The temperature of these springs was determined in 1894 by Capt. Purey-Cust to be between 100° F. and 107° F.

Hot springs on the island of Efaté, $\frac{1}{4}$ mile to the north of Quoin Hill; again on the N.W. of Meli Bay, where hot water is reported to ooze out of the sand between the tide-marks.

Investigating the former of these latter two, we found warm water oozing out of a considerable area of low-lying ground, resulting in the formation of a swamp connected with the sea. The water was running only very gently, and the temperature such that the hand could be immersed for half a minute without

* The Rev. J. Atkin, in 1868, described the islands of Vanua Lava and Gaua as active volcanoes; this is evidently a mistake.

† The Rev. S. Ella reports the presence of a boiling spring on the island of Gaua. This we were not able to verify.

inconvenience. In the rainy season, however, the flow is reported to much increase, and at the same time to rise considerably in temperature. A quantity of white saline material is deposited as an earthy encrustation in the vicinity, and studding the shallow swamp are innumerable carcasses of boiled land crabs which have been unfortunate enough to fall in. Surrounding the spring is a glade a couple of acres in extent devoid of trees or scrub. Closely investing this grassy clearing, and contrasting strongly with it, is a dense jungle of stunted vegetation.*

EARTHQUAKES are of regular and frequent occurrence, often assuming a violent character. Most, undoubtedly proceed from the local volcanoes which, when they increase in activity, are in a constant state of tremor, punctuated at intervals by severer shocks, felt at considerable distances.

To give an idea of their frequency at such times, it is interesting to note that, after the outbreak of Ambrym in 1894, shocks were felt every ten minutes on board H.M.S. 'Dart' anchored at Dip Point; later on as she steamed over to Malekula, shocks continued to be felt at repeated intervals by those on board, even when in the open sea; again, whilst at anchor at Port Sandwich, thirty shocks were felt in a single night.

At other times shocks are much less frequent, and several weeks may go by without even a tremor.

During our visit, amongst those experienced, two were of special interest. One of these was a sharp shock felt at Tangoa at 12.25 a.m. on July 29th, followed at 1.15 a.m. by a smaller shock. These shocks were accompanied by much noise, and several articles were thrown down from the cupboard shelves in the Mission houses.

The other of these two happened at 6.30 p.m. on August 28th, and was experienced under novel conditions. We were out at the time in a canoe on Erakor Lagoon, when the boat suddenly received a shock accompanied by a sound just as if it had been

* This feature recalls that reported by Lieut. Frederick as existing under similar conditions in the vicinity of the hot ground on Tongoa.

struck sharply from below. Indeed, although there seemed to be quite 4 ft. of water under the keel, it was our impression that the boat had been bumped on the coral. Captain Rason who, at the time, was at the Residency some two miles away, noting the direction of swing of a hanging lamp, decided that the shock must have travelled in a more or less east and west direction.

Earthquakes of a much more alarming character are felt at longer intervals. As an example, one which happened several years ago, and was severely felt right through the Group, might be mentioned. Accompanying this shock permanent fissures were formed in the ground in certain localities, several wooden buildings were demolished, iron tanks were thrown down and burst, and, in the Mission premises, pianos and heavy furniture were flung across the rooms.

With regard to the origin and direction of travel of these shocks it is a lamentable fact that so little accurate knowledge is obtainable.*

Undoubtedly most of the shocks travelling in a general N. and S. direction originate from the active volcanoes; many, however, result from a continuation of the cross-faulting. Those with an east and west swing are most probably due to flexional movements, originating no doubt in the deep abyss between the New Hebrides and New Caledonia.

It is sincerely to be hoped that before long numerous seismological stations will be distributed through the South Pacific Islands, as only by analysing such data as would result, can definite decisions regarding the present earth-movements in this much-troubled area be arrived at.

Summarising this section the following points deserve special attention :—

1. The extreme importance of volcanoes and materials derived therefrom in the formation of the islands of the New Hebrides.

* All available material is due to the Rev. W. Gray, and is to be found in A.A.A.S. Reports.

2. The arrangement of the volcanoes in definite directions; older andesite extrusions along the septum of a great fold which has defined the land-surface of the Group, followed later by basic eruptions on the inner wing along a line approximately parallel to the former. A tendency for subordinate arrangement of cones along cross-fractures is only imperfectly marked.

3. The immense size of many of the Pliocene and recent craters.

4. Differentiation in the magma reservoir resulting in andesite lavas preceding more recent basaltic flows.*

SEC. 3. MINERAL RESOURCES.

Reports of rich prospects of nickel and copper ores in the New Hebrides have been widely circulated, and were readily believed on account of the proximity to New Caledonia.

Since, however, the vastly more recent age of the New Hebrides has been demonstrated, such announcements must be taken *cum grano salis*. Traces of these minerals are no doubt to be found widely distributed through the Group, but we do not think that any payable deposits exist above sea-level.

These remarks do not apply to deposits of sulphur and of magnetic iron, which are extensive, and will in the near future undoubtedly command considerable attention.

Sulphur deposits† are developed in the neighbourhood of Yasowa on Tanna and at the fumaroles on Vanua Lava; the latter deposits are much the more important.

Magnetic iron sand similar to that of Taranaki in New Zealand occurs in large quantities on the beaches of many of the islands. A fairly rich sample collected at Meli Bay, Efaté, without undergoing concentration gave the following results:—

Fe	...	45·6°.
TiO ₂	...	3·5°.

thus accounting for over 66% of the material when calculating

* Judging by analyses of lavas recently erupted from Yasowa, it would appear that the latest phase is again that of an andesite magma. Note that East Indian volcanoes are now also ejecting andesite.

† See reports by M. Pelatan.

the Fe as Fe_3O_4 . On account of its high titanium content and fine character this ore is practically useless at the present moment, but with success of experiments on titanium steels now in progress, might at any moment assume commercial importance.

Some of the finer non-calcareous bands in the *Efaté Soapstones* would make an excellent abrasive for polishing metals, and as the cost of mining would be only nominal, good results might be expected from such an enterprise.

With respect to guano deposits, our discoveries were restricted to scattered bodies of bat guano occurring in caves penetrating the recent coral limestone. These deposits were found both in Santo and Efaté, but on account of the distance apart and of their small dimensions—the largest of them containing a few hundred tons only—they will never be of much commercial importance.

Numerous small samples of copper, manganese, and other ores supposed to have been collected in the Group, were examined by us, but as nothing further was ascertained of their occurrence they do not warrant further mention.

PART II.—SEC. I. DETAILED GEOLOGY OF EFATÉ.

i. SUBMARINE VOLCANIC ORIGIN (Refer to Plate xxviii.)—The island of Efaté owes its immediate origin to extensive submarine volcanic activity resulting in the piling up of thick beds of tuff, which, later on, effectually hidden beneath a veneer of coralliferous limestone, were raised to heights above sea-level. Over the greater part, so perfect is this limestone veneer, as to lead the casual observer to believe it to be a purely coral island.

Careful examination discloses the fact that, underlying the coral limestone at short distances, are fine-grained submarine tuffs, shading off below into coarser varieties, in which distinct fragments of a white pumice are visible; in other parts of the island massive agglomerates are developed below the coral.

As regards the location of the original crater, it would undoubtedly be situated in the neighbourhood of the coarser ejectamenta. Bearing this in mind, and recalling the distribution

and general dip of the rough bedding planes of the agglomerates at the north-east corner of the island, we were early led to consider Undine Bay as the remnant of an old crater whose lip ringed in the islands of Nguna and Mau, which, on this hypothesis, would be daughter-cones standing in the old crater, as do Mts. Benbow and Marum in the crater of Ambrym.

Although the evidence supporting this view seemed at first sight conclusive enough, yet, when further attention was paid to the character of the rocks, it was at once evident that the Undine Bay agglomerates are, for the most part, to be referred to the later basic eruptions, and could not be reconciled with the andesitic pumice tuffs of Havannah Harbour and elsewhere.

It seems probable, therefore, that several smaller vents now largely obliterated by later extravasations of more basic lavas and agglomerates, contributed to the earlier series of andesitic eruptions. One of these craters must have been situated in the vicinity of Havannah Harbour.

ii. COARSE PUMICE TUFFS.—A coarse tuff composed of fragments of an ashy-grey pumice with occasional pieces of a dark-coloured glass forms the base of the series. At Havannah Harbour (see Section, Plate xxiv.) where these beds are so well developed, they are coarsest at sea-level, containing fragments up to 4 inches diameter; above, at an elevation of several hundred feet, they pass into a finer-grained rock which has all the essential characters of the Fiji soapstone; this succession is repeated several times at higher levels. Examination has shown that these tuffs are referable to an andesite lava; the fragments are in every respect similar to the light grey pumice found at the present day drifting in the Pacific, derived from submarine volcanoes distributed along the great fold-area further to the east. Analysis of some of the perlitic glass (Sec. 3, § 5) contained in these tuffs shows that it is similar in composition to the pumice, though slightly more acid.

iii. THE SOAPSTONE SERIES.—The fine-grained beds noted in the last paragraph as being similar to the soapstones of

Fiji are so extensively developed as to form the most important horizon, after the limestones, outcropping on the island (see Sec.3, §1). They represent deposits of the finer material from the same eruptions as were derived the coarser fragments of the associated pumice tuffs. The differentiation is due partly to the varying degree of buoyancy of the material causing the finer to settle last, and largely to the fact that, subsequent to the sinking of the denser pumice, a vast amount of fine powder would be continuously showered down, derived from the attrition of extensive fields of the lighter floating material. Several successive repetitions or the passage of coarser into finer tuffs were noted, each probably connected with a separate outburst.

It is probable that beds in the upper part of the series owe their origin to the later basic eruptions of Undine Bay and to seas of floating pumice drifting from other localities.

The fine-grained beds of the soapstone series are extremely well bedded, contrasting strongly with the almost massive pumice tuffs; where the dip, undisturbed by faults, could be measured, it was generally found to be a small angle in towards Undine Bay.

Well in towards the centre of Efaté, at Antonio's plantation, where an outcrop of the soapstone was examined, an interbedded band of calcareous rock* two feet in thickness, composed almost wholly of tiny foraminifera and one specimen of *Dentalium*, was noted; this find is of special interest, as it was the only locality where fossils other than *Globigerina* were found in the soapstone.

For the most part the soapstones are fossiliferous and only slightly calcareous, the materials contributing to their formation being chiefly glass fragments and to a less extent mineral fragments, chiefly felspar. Often amongst the finer soapstones occasional rounded pellets of white pumice are to be found, evidently representing water-logged particles.

* Mr. F. Chapman, to whom a slide of this rock has been forwarded, states that it contains no forms such as would definitely fix its age. The absence of the larger forms like *Lepidocyclina*, he thinks, refers it to a later period than the Miocene.

iv. **THE AGGLOMERATES.**—At Undine Bay,* outcropping from near sea-level to elevations of about 2000 ft. (Plate xiv.) is a thick series of agglomerates composed of fragments of rock similar to the basic lavas of Mau and Nguna. This series appears to overlie the more acid pumice tufts met with further to the west.

In some of the gullies where sections of these rocks are obtained, bedding planes varying considerably in dip within short distances can be seen, representing the surface slope of deposition. The rounded volcanic boulders composing the agglomerate were found up to 2 ft. in diameter, and represent a variety of types from that of a basic andesite to a basalt, usually cellular and invariably retaining a certain amount of glass base.

Crossing the agglomerate beds, generally along the planes of deposition though to a less extent in every possible direction, are very numerous dykes and sills of porphyritic basalt (Sec.3, §8) measuring up to 30 ft. in thickness. These intrusions must have taken place at a comparatively late period, as they were found intruding the older coral cappings in the vicinity; their injection was probably contemporaneous with activity in the vicinity of Fatmalapa, where a small centre of eruption seems to have been developed synchronously with those of Mau and Nguna.

v. **THE RAISED REEFS.**—Capping all the formations previously described are beds of coral limestone, probably seldom exceeding 50 ft. in thickness, but developed on such an extensive scale as to leave little of the underlying foundation-rocks exposed (see Sec.3, §2). Two of these raised reefs, somewhat older than the others, cap the agglomerate hills to the south of Undine Bay, and have been intruded as mentioned in the last paragraph. The upper of these can be seen in the photograph (Plate xiv.) at an elevation of over 2000 ft., forming the crowns of the hills.

Below, at an elevation of 1000 ft. and upwards, is the second development of older reef-limestone, which in the vicinity of

* See Plate ii. in 'Preliminary Note.' Report A.A.A.S. x. 1904.

Fatmalapa appears to be overlaid by a couple of hundred feet of tuffaceous agglomerate.

Newer raised reefs occur at intervals in terrace-formation down to the beach,* evidently marking a succession of sea-levels resulting from sudden uplifts of the land, probably quite parallel with those recorded at Port Resolution within recent years. When the time that elapsed between any two succeeding uplifts was considerable, the resulting coral reef-growth would be correspondingly extensive; in a case where several lesser upheavals taking place within a few years of each other have contributed to the total elevation, little trace of these intermediate beach-lines could be expected preserved now, after exposure to a tropical denudation for many years. Special attention was paid to this point, and as a result we are able to say with certainty, from the evidence of corrosion-marks in the terrace-faces, that at any rate the more recent of them were elevated by a succession of minor upheavals following each other at intervals, very short compared with the periods of time elapsing between the major upheavals resulting in the formation of distinct terraces. The evidence of these minor uplifts is only faintly marked, even in the case of the more recent upheavals; it has been completely obliterated in the older raised reefs.

On account of the steep shore-slope and continuous upheaval, the reefs have narrow platforms which are usually level or even gently rising towards the land; where the platforms are wider, however, they may be noticeably depressed on the landward side, indicating the existence formerly of a calm-water channel.

Most instructive sections of the coral veneers are exposed in several localities where they have been cut through by torrential watercourses, notably at Steep Gully (Plate xxiv.). Such sections show that after an upheaval, the coral begins to grow in the shallower water, building directly on the solid rock below, or, as is more often the case, separated from it by a few feet of beach sand or beach pebble conglomerate. As the reef continues to

* See Plate i. in 'Preliminary Note.' Report A.A.A.S. x. 1904.

grow it extends outward on a platform of foraminiferal and shell limestone containing frequent blocks of coral broken off from above. In this way, owing to the steep shore-slopes, a face of coralliferous limestone 300 ft. or 400 ft. in height may be rapidly built up.

vi. LATER BASIC ERUPTIONS.—The extrusion of the basic lavas composing the islands of Nguna, (Plate xvi. fig.1) Mau (Plate xv.) and Pelé is here made the subject of a separate paragraph, but must be regarded only as a later phase in a sequence of events beginning with the accumulation of the thick series of agglomerates on the mainland.

The lava-types are quite similar in both localities, but the outlying islands undoubtedly remained active long after the mainland had become extinct. Proof of this latter fact is evidenced by the well preserved shape of the cones and the absence of limestone at any considerable elevation on Nguna, Mau and Pelé. On the mainland three distinct coral limestone terraces are distinguishable (Plate xiv.) overlying the agglomerate beds (their growth therefore post-dating the basic eruptions of the mainland) and dipping down towards the east; no trace of these is observable on the lava-slopes of the neighbouring islands, which fact seems to show that elevations of the mainland were contemporaneous with activity in the latter localities.

The rocks of this series are almost all solid lavas, basalts and basalt porphyries (Sec.3, §7). At the southern extremities of the islands only is there any notable development of raised coral, and that of limited extent and elevated a few feet.

vii. RIVER ALLUVIALS.—Owing to the soft nature of the submarine tuffs so extensively developed on Efaté, river-erosion is comparatively rapid, resulting in the formation of considerable areas of alluvial flats at the extremities of the larger streams.

The soil composing these flats contains, in addition to strippings from the tuffs and agglomerates of the hills, a large proportion of marine material admixed with it, indicating that deposition took place largely in sea water, and that consequently recent upheaval must be responsible for its present elevated position.

LOCAL FEATURES.

VILA.—In the vicinity of Vila the hills are low, seldom exceeding 350 ft. in height; almost all the outcrops are of coral limestone, and though so near the surface very little is seen of the underlying soapstone. Similar low hilly country occupies the whole of the southern division of the island.

Directly behind the township is an arm of the sea, Erakor Lagoon, encircled for the most part by coral-covered hills 350 ft. in height. This coral limestone is not more than 100 ft. thick, being underlaid by soapstone beds, found outcropping best in the vicinity of Largeaux's plantation, where they dip 8° S., 60° W.

SHEPHERD'S HILL, a prominent feature of the south side of Vila Harbour, is a raised reef, at first sight apparently wholly

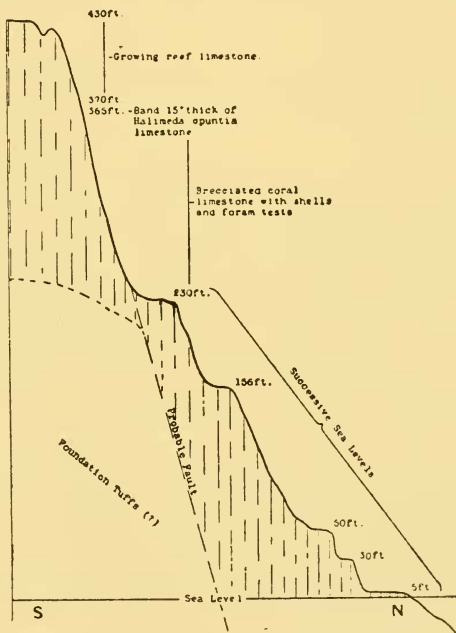


Fig. 4. Section of the north face of Shepherd's Hill, Efaté.

built up of coral limestone material. At its eastern end where it was examined (see text-fig.4) it rises very steeply to a height

of 430 ft., then slopes away gradually to the south. The steep northern face, we think, is due probably to a fault, though little direct evidence of such is obtainable. The discovery of a few derived pebbles of fine-grained tuffaceous rock at about 230 ft. level indicates the proximity of underlying foundation-beds to the surface. In the section several newer coral limestone growths are indicated skirting the lower slopes. In all, three zones are differentiated :—

1. The old coral reef capping the hill and yielding—
Corals—1, 4, 18.
2. The foundation-beds of the old reef yielding—
Pelecypoda—2, 10, 25.
Gastropoda—9, 15.
Alga—1.
Corals—2, 12, 14.
3. The newer veneers at lower elevations yielding—
Pelecypoda—21, 30.
Corals—9, 19.

MELI DISTRICT.—Extensive alluvial flats as much as two miles in width are developed here. At the foot of the Tripple Top Mountain in the bed of a river deeply scored in coarse pumice tuffs, pebbles of glassy andesite were found, indicating proximity to one of the old andesite vents; other pebbles, found to be varieties of submarine tuff, were composed of fragments of soapstone-like rock and organic remains, amongst which *Conocyathus* sp., and *Lima* sp. were recognised.

HAVANNAH HARBOUR TABLELAND.—This we found to be one of the most excellent examples of raised coral reef-formations imaginable (Plate xix., fig.1). A more complete examination than we were able to carry out in our limited time, could be readily accomplished, by working on the magnificent exposures in the steep cliffs of the Ai Stream gorge, and should be of the greatest interest.

Several traverses were made in the most promising directions. The first was up Steep Gully (Plate xxiv.) to the west of the Ai

Stream. The second was along a track leading from White Sands to the village of Saone,* then back by the steep gorge of the Ai Stream (text-fig.5).

A third traverse run across the tableland from Meli Bay to Havannah Harbour gives a good general idea of the surface-contour and terrace-formation (text-fig.6, p.444).

Much faulting is to be expected in a region such as this, where thick beds of soft rocks are developed close to volcanic centres and where orogenic processes are actively in progress. In the Steep Gully section a fault with a down-throw to the north was noted; this same fault, though not proved in the

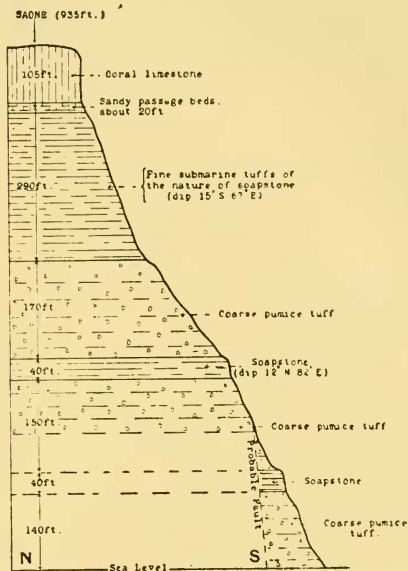


Fig.5. Section of the beds underlying Saone as exposed in the Ai Stream gorge.

Ai Stream traverse, may have thrown down the 40 ft. bed of fine tuff, thus duplicating it in the section.

These faults ante-date the development of the coral veneer, and so do not show on the surface; for this reason and from the fact that suitable outcrops were not always available, other faults may have been omitted from our sections.

LELEPPA preserves the same general characters exhibited on the adjacent mainland. Coarse pumice tuff, with fragments of brown glass, persists to an elevation of 250 ft. Above this is a yellowish submarine tuff composed of numerous fragments of marine organic remains in a fine-grained soapstone-like base; this rock is similar to the fragment found on the mainland in the

* For surface sections of terraces met with on this occasion, see 'Preliminary Note' in Report A.A.A.S., 1904.

Meli District. Above the 280 ft. level outcrops of coral limestone were alone observed.

There are two large caves on the island. One near the north-east corner runs in the recent raised coral at an elevation of

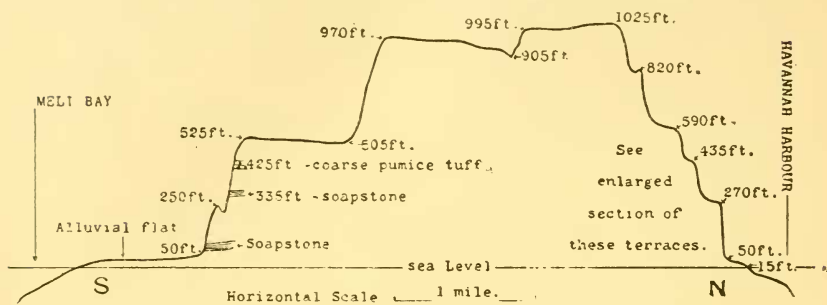


Fig. 6. Traverse across the Havannah Harbour plateau.

about 30 ft., penetrating for a distance of 120 yards, though only quite narrow after the first 40 yards. Another in the south-west corner excavated in the coarse pumice tuff is in the form of a dome, 40 yards in diameter and quite 80 ft. high. It has a small entrance 50 ft. above sea-level, and thus presents the appearance of a huge bee-hive. It has no doubt been formed by the sea eating away some soft bed below, causing the unsupported tuff originally forming the interior of the dome to subside.

ERRADAKA and Moso are similar, geologically, to Leleppa Island, and with it are probably separated from the mainland by a subsided area giving rise to Havannah Harbour.

UNDINE BAY DISTRICT.—Several excursions were made to the hills in this vicinity, with results incorporated in the section (text-fig. 7). The limestones of the two upper raised reefs are quite similar to each other, and much older in appearance than that composing the lower terraces. When making the ascent of the highest hills along the track shown in the map, outcrops of a similar limestone, much intruded by porphyritic basalt, (Sec. 3, §8) were continually met with at intervals between the horizons of the two older raised reefs. From this fact, and judging by the contour of the land-surface in the vicinity, (Plate xiv.) it is

probable that an extensive fault* has been developed along the face of what are now the highest hills, letting down the north side.

On this assumption, the lower development of older raised coral limestone would not be a separate horizon, but merely a subsided portion of that outcropping above.

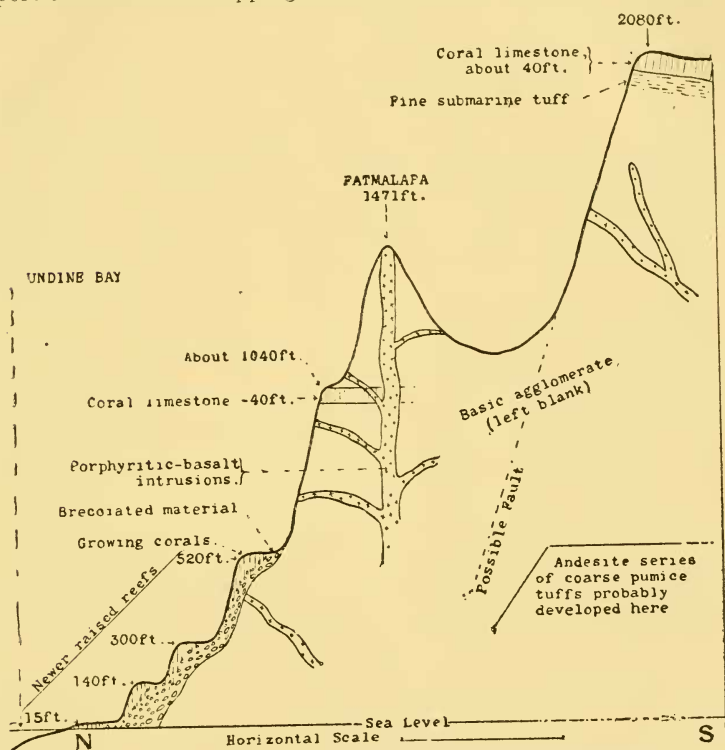


Fig.7. Section through the hills south of Undine Bay, Efate.

Contemporaneous with this faulting would be lava-intrusions and the extrusion of volcanic material in the vicinity of Fatmalapa.

* This fault seems to have crossed the older crater which had yielded the agglomerate beds. Its direction, traced by the topography of the hills, seems to have been peripheral, with Nguna as centre.

NGUNA, MAU and PELE (Plates xv., xvi. fig.1, xvi. fig.2) are built up of basic lavas (Sec.3, §7) and call for no special description. One point perhaps worthy of note is revealed on the north-east coast of Pelé, where part of the old crater-lip has been broken down, revealing beds many feet in thickness of a fine-grained volcanic ash apparently developed under water and later overlaid by further flows of lava.

SEC.2. DETAILED GEOLOGY OF SOUTH-WEST SANTO.*

i. THE EARLIER VOLCANIC SERIES.—The oldest rocks met with in Santo are thick beds of agglomerates and tuffaceous rocks developed in the Puria Etsa District on the west coast of Santo. In this locality they are at least 400 ft. thick (above sea-level), built up of fragments of andesitic lavas largely glassy. They are of a greenish-grey colour, due to the development of much chlorite, which gives them a decidedly older appearance than the more recent agglomerates of the Wai Bubo and La La Vura. Below they are coarsest, much crossed by veins, often several inches thick, of white to greenish secondary minerals resembling zoisite in physical properties; above they are much finer and split up readily along numerous cleavage directions until reduced to the smallest fragments.

As regards age, they are no doubt early Miocene, for they appear to pass up regularly into the *Lepidocyclina*-*Lithothamnion* limestone above.† Thick beds of agglomerate observed outcropping in the cliffs along the coast southward from Sauri'i to C. Babana are no doubt referable to this same series.

ii. MIOCENE *LEPIDOCYCLINA*-*LITHOTHAMNION* SERIES.—These beds occupy large areas in south-west Santo, where they are highly tilted and intruded by andesites of the later volcanic series. In their lower portions they are fine-grained dark grey tuffaceous rocks containing occasional radiolaria

* Refer to Plate xxix. for map.

† A more thorough examination of these beds is desirable, as on account of faulting the evidence obtained of their relative age was not altogether satisfactory.

and small Globigerina; above, the foraminiferal remains become relatively more numerous until beds of nearly pure limestone (Sec.3, §3) up to 20 ft. in thickness are met with. Much of the upper portion of the series was hidden from view in the sections examined by us; such outcrops however, as were available, proved to be coarse fragmentary types in which pebbles of foraminiferal limestone and andesitic volcanic material figured.

The series is much faulted and intruded by hornblende and pyroxene andesite; interbedded bands 30 to 40 ft. thick of andesite agglomerate were also noted.

In most localities the beds dip in towards Losubunu at angles varying between 27° and 53° ; further west (the Wai Bubo outcrop) (Plate xix.) they are completely reversed, dipping 55° S., 17° W. The total thickness of the Miocene beds exposed on the Wai Bubo is probably not less than 800 ft.

iii. LATER VOLCANIC SERIES.—After a considerable period of subdued activity, allowing of the accumulation of the bedded Miocene limestones, intense folding and faulting seems to have taken place, accompanied by extensive extravasations of andesite lavas (Sec.3, §6) and agglomerates. On the Wai Bubo thick beds of dark grey tuff (Sec.3, §4), composed mainly of mineral fragments, through which are scattered occasional Globigerina tests, are interbedded with this series, and dip uniformly 27° due S.

The lavas are usually pyroxene andesites, though more basic varieties, especially among the later flows, are not uncommon, as, for instance, an olivine pyroxene andesite from the base of Lobweri, and several basalts outcropping between Tasiriki and C. Ukuani.

In the vicinity of the Losubunu the total thickness of this series cannot be less than 5000 ft.

iv. BEDDED ROCKS UNDERLYING THE RECENT RAISED REEFS.—The foundation-rocks immediately underlying the recent raised reefs in Santo, are similar to those found elsewhere in the Group, and vary in character from types similar

to the Efaté soapstones, to coarser littoral deposits like the fossiliferous cinder beds of the Foreland, Epi. At Tasiriki, are developed beds intermediate in character between these two, containing abundant marine fossils; a little further to the north, at C. Ukuani (Plate xx.), they are seen passing down insensibly into the agglomerate. On the Atsone is an evenly bedded light yellow variety, dipping 8° S., 70° E., and texturally resembling soapstone, though composed so largely of *Globigerina* tests as to deserve the title of *Globigerina* ooze.

Occasionally, as for example on the north side of the Wai Bubo near the ford, the recent limestone rests either directly on the agglomerates, or is separated by a few feet only of drift sand rock.

The regular dip of these beds is about 8° in an easterly direction, showing that since the cessation of the lava-extrusions of the later volcanic series, orogenic movements have been of the nature of almost horizontal uplifts. Where we had an opportunity of examining them, these beds did not exceed 100 ft. in thickness; there is little doubt though that in east Santo, where they are thickest, they are to be measured in many hundreds of feet.

V. RECENT RAISED REEFS.—The recent raised coral reefs are most extensively developed in the eastern portions of the island, where they form an immense elevated tableland sloping gently downwards in a south-easterly direction. The island of Araki and the hill Tumebu (Plate xxi.) are outliers of this formation, exhibiting the characteristic steep slopes descending in three major terraces.

Towards the west coast the regular terraces lose their distinctiveness owing apparently to considerable faulting having taken place since the coral limestone was formed.

In the Tano Busi district coral limestone was traced to elevations of about 1000 ft. Further north it becomes scanty (Plate xvii.) and past C. Ukuani does not appear at all at heights exceeding more than a few feet above sea-level. At C. Karai to

the north of Wuss, raised coral limestone encrustations appeared along the shores at elevations of 12 ft. only.

vi. RECENT FRESH-WATER DEPOSITS.—On the banks of the Atsone River, about two miles from the mouth, beds outcrop quite 30 ft. in thickness composed of fresh-water drift material, mostly matted leaf-remains with fairly numerous fresh-water shells. Their deposit was formed prior to the latest upheaval, which gave the river a chance to cut a channel through its earlier sediments. Similar deposits are developed in greater or less extent near the mouths of all the more important streams. Along the valley of the Navaka for a considerable distance from its mouth are great flood-deposits a quarter of a mile in width, of volcanic boulders and pebbles brought down from the high mountains to the north.

Another deposit relatively unimportant is that of travertine encrusting the beds of creeks which traverse limestone regions. Leaves of trees, sticks and other matter happening to fall into such streams are after a time, as they rot away, reproduced as negative casts in travertine.*

vii. EVIDENCE OF FAULTING IN SANTO.—Along the west coast considerable faulting has taken place, resulting in much complication of the geology.

The general features of the district south of Wuss suggest peripheral faulting around Losobunu, developed most strongly in a N.N.W. direction; crossing this series there appears to be radial faulting, allowing the rivers a ready passage to the sea. An example of this type is seen at Sauri'i, evidenced by the discordance of the rocks on either side of the narrow river valley. A further example is very noticeable crossing the agglomerates on the cliffs a little north of Pareo. As indicated by the direction of trend of the ridges on the eastern side of Losubunu, peripheral faulting, no doubt, extends in that direction also.

* Dr. Guppy noted the same thing occurring in Solomon Island streams.

The complete reversion of dip in the thick series of Miocene rocks exposed on the Wai Bubo argues extensive folding, followed by faulting probably overthrust in a westerly direction.

A few hundred yards inland from Tasiriki is a well exposed fault trending in a N.W. direction. This fault is much newer than those previously mentioned, as it cuts across the raised coral limestone.

LOCAL FEATURES.

TANGOA, like the other small islands so numerous along the east and south-east coasts of Santo, is built up completely of coral reef débris. On the mainland, opposite, a broad flat averaging one mile in width, composed mainly of river débris, leads to the foot of the coral terraces 800 ft. to 900 ft. in height.

Pebbles collected in the Atsone River, some distance from the mouth, proved to be of no special interest, with perhaps one exception—that of a sedimentary rock composed largely of volcanic ash, and containing very abundant organic remains, notably *Halimeda opuntia*.

ARAKI is an exact counterpart of the hill Tumebu (Plate xxi.) on the mainland adjacent. On the east side at an elevation of about 200 ft., just below the second terrace, there is a fair-sized cave running into the coral limestone for a distance of 100 yards. In it we collected a few specimens of stalactites, the first we had met with in the New Hebrides. A considerable quantity of bat guano, estimated at 14 tons, covers the floor at its inner end for a depth of one foot, six inches.

TASIRIKI TASMALUM TRACK.—From Tasmalum the track crosses a low raised reef limestone plateau not exceeding 100 ft. in height descending later on into the bed of the Navaka. About $\frac{1}{4}$ mile walk over the pebbles and sand banks brings one to the opposite side, where the track leaves the river and commences a long ascent. At this spot a good outcrop of fossiliferous soapstone-like foundation-beds dipping 8° S., 83° E. appears, capped a short distance above by raised reef limestone. The ascent continues until within $1\frac{1}{2}$ miles of the ford on the Wai Bubo; at this point it has reached an elevation of close on 1000 ft.

As the track proceeds it descends rapidly to the bed of the Wai Bubo, passing downwards from foundation-beds of the soapstone class over massive agglomerates and interstratified tuffs to unconformable Miocene limestone (208, 210, 211c, 212, 223) tilted at an angle of 55° , so well exposed along the river banks (Plate xix.). Further on, nearer to the ford, better exposures of the mineral tuffs (Sec.3, §4) dipping 28° due S. are obtained capping the older Miocene series. At the ford, on the north side, the mineral tuffs are replaced by agglomerate beds which are capped directly above by the recent coral limestone.

TASIRIKI itself is within easy distance of many interesting spots. Immediately above the cove on the hillside are soft foundation-beds yielding very numerous fossil forms, amongst which the following have been recognised:—

Brachiopoda—1.

Pelecypoda—1, 5, 6, 8, 15, 16, 18, 20, 21, 27, 28, 29.

Scaphopoda—1, 2.

Gastropoda—1, 2, 3, 4, 6, 7, 10, 11, 13, 14, 16, 17, 18, 22, 23,
25, 27, 28, 29, 30, 31, 32, 33, 36, 37, 40, 42, 43.

Pteropoda—1, 2, 3, 4, 5, 6.

Hydrocoralline—1.

Coralline—3.

Echinoidea—1.

The rocks forming the southern breakwater to the bay are an interesting type of conglomerate, in which water-worn volcanic pebbles several inches in diameter, such as constitute the beaches in the vicinity, are bound together by calcareous organisms. Above, where the pebbles become less numerous, corals make their appearance.

To the north on the hills behind Penanbo, and as far as C. Ukuani, lavas and agglomerates make their appearance underneath the foundation-beds. Specially good outcrops of these are obtained in the vicinity of C. Tsinone; here they contain occasional fragments of limestone, which, however, has lost any trace of organic structure.

TASIRIKI TO TALAPONE (see Plate xxv. for Section)—Our track lay through Penanbo, then over the coral terraces in a fairly direct line to Partua Tabua. Soon after leaving the village of Narerea the plateau of more recent rocks was left behind, and the steep ascent of Partua Tabua begun over Miocene rocks with occasional outcrops of andesite and tuffs. The descent on the far side was steeper than the ascent, until finally the creek below Maliu was arrived at, where outcrops of agglomerate were noted. From this point the track rises in gentle stages to La La Vura.

The rocks in the vicinity of our headquarters at La La Vura proved to be mostly agglomerates, with occasional flows of olivine pyroxene andesite. At higher elevations hornblende andesites and pyroxene andesites were continuously met with until we finally arrived at the neck of land separating Lobweri from Talapone. Here a small outcrop of mineral tuff was noted. Further on, after passing over the andesites of Talapone, we again met with outcrops of these mineral tuffs, which, from their similarity to those found on the Wai Bubo, are probably of submarine origin, arguing a subsequent upheaval of quite 4000 ft.

On our return journey we met with an outcrop of Miocene limestone between Lobweri and Partua Tabua (133), followed by outcrops of volcanic rock, and again, further developments of the Miocene series (134) at an elevation of about 1500 ft. From this point down to the meeting of Dry Creek and the Malikoliko continuous outcrops (176, 178, 182) of the Miocene beds were met with. Just at this spot they have been intruded by a hornblende andesite (Sec. 3, §6), which near its junction with the intruded rocks, passes into a pyroxene andesite.

Beyond, outcrops of andesite are met with until near C. Ukuani, where the recent coral limestone predominates.

Several fossils of this limestone proved to be :—

Corals—7, 17.

Gastropods—14, 41.

Wuss, on account of its situation, handy to mountainous country, is a particularly interesting locality. Good sections of steeply dipping Miocene tuffaceous rocks are to be noted on every

hand, with a general dip inwards to the land side. Near C. Karai they are intruded by a glassy hypersthene andesite.

In the Puria Etsa district agglomerate beds are developed apparently underlying the bedded Miocene series.

In this promising locality beach and river pebbles were diligently examined in the hope of finding traces of the gneiss reported to be largely developed in this locality. The search proved fruitless, however; the only rock-type discovered not already found, occurring *in situ*, was a pebble of a biotite hornblende andesite.

SEC.3. PETROLOGICAL DESCRIPTIONS.

i. EFATE SOAPSTONES.—Under this title are grouped a variety of fine-grained submarine tuffs, so named on account of the resemblance which typical specimens bear to the well-known Fiji Soapstone. They are well bedded, differentiated into alternating coarser and finer bands, the former of which occasionally pass over into a coarse pumice tuff. Endless varieties are further produced by the introduction of varying quantities of organically derived calcium carbonate which is present usually as *Globigerina* tests, though in one locality quite a variety of the smaller forms of the foraminifera were observed.

Distinctive features of these beds are softness, friability, earthy odour, greasy feel of the finer samples, and, above all, marked absorptive properties. If a dried sample be placed in water it immediately sinks, and, as it continues to absorb moisture, streams of tiny air bubbles are given off, accompanied by a fizzling sound. In the case of the yellowish samples (the most greasy and probably the more basic) subsequent drying, even slowly in a normal atmosphere, causes them to crumble up.

In colour they vary from a pure white to shades of yellow and grey, usually ashy-grey. Brown manganese stains are sometimes observed, more commonly along the joints. Apparently homogeneous samples will as a rule, on more careful examination, be found to contain coarser and finer bands often only a few millimètres thick. These finer bands represent material of the

nature of the finest dust, the particles never exceeding 0·02 mm. diam.; the fragments in the coarser bands average 0·08 mm. diameter. Fragments of volcanic glass and pumice, and in small quantities felspar granules, are invariable constituents; accessories are particles of magnetite and pyroxene, and organic remains, chiefly tests of small foraminifera.

One variety noted in the series differs rather widely from the type-specimens, and deserves special mention. It outcrops as a compact band a few feet in thickness at the 300 ft. level in the gorge of the Ai Stream. It is quite hard and much coarser in texture than usual. *Felspar* referable to andesine constitutes about 8 % of the rock and is present as fragments sometimes 1·5 mm. diam.; about another 1 % is represented by *augite* and *magnetite* in very small grains; the rest of the section consists of irregular particles of fibrous *volcanic glass* and *pumice fragments* much infiltrated by calcium carbonate, and attaining a maximum length of 1·5 mm.

Professor Liversidge has recorded the analysis of a specimen of a rock collected at Havannah Harbour, from a terrace at an elevation of 525 ft. The rock is described as greyish-white in colour and readily friable. This can be no other than the Efaté soapstone.*

ii. RAISED REEF LIMESTONE.—This limestone is built up of the fossil remains of calcareous reef-haunting forms of life, amongst which the corals figure conspicuously. In most instances it is so recent that the cell-cavities have not yet been filled up, nor has the intimate structure been lost. Tracing the reefs back from newer to older, the limestone becomes noticeably more compact with obliteration of cell-spaces and development of crystalline calcite. No true dolomites were observed.

Often a more darkly coloured layer resembling dense travertine appears as a facing half an inch or more in thickness; this seems to have resulted from concentration of the more insoluble parts of the limestone by percolating water.

* Journ. Proc. R. Soc. N. S. Wales, xiv. 161 [1881].

The limestone from the lower portions of a reef is always fragmentary, and though invariably coralliferous, may often be most largely composed of remains of mollusca, calcareous algæ, and foraminifera, with a cement-like base of calcareous mud; in addition a small percentage of inorganic matter is often present, resulting in a greater or less degree of staining.

In the upper part of the reefs is a zone, never relatively very thick, where prior to elevation the polyps thrived—here the limestone is quite white and is composed of large upright heads of coral.

Dr. Hinde examined two specimens of coralliferous limestone from the raised reefs of Efaté and found *Lithothamnion* contributing largely to its formation.

Professor Liversidge has also recorded analyses of two samples of raised reef limestone from this locality.†

iii. **LEPIDOCYCLINA-LITHOTHAMNION LIMESTONES.**—Lepidocyclus-Lithothamnion limestones of Miocene age are found widely distributed both in Santo and Malekula. On account of their greater compactness and even fracture, they are readily distinguishable from the more recent coralliferous limestones just described. Among the most conspicuous of the organisms* represented is *Lepidocyclus*, specimens of which are common, 6 mm. in diameter; branching and encrusting forms of *Lithothamnion* are also present in considerable quantity.

Inorganic matter of the nature of mineral fragments and pellets of volcanic rocks are always present, though in variable amount, resulting in varieties differing considerably in colour and composition. The purer types are almost white, but far more common is a light grey to plum-coloured limestone, containing upwards of 20% of inorganic matter.

† *Loc. cit.* p.160.

* For microphotographs, a complete list of the forms present in these beds, and for detailed descriptions of several of the specimens, see Mr. Chapman's paper (*antea*, p.261).

No dolomites were observed, though some of the beds, 'no doubt, run high in magnesia, as contraction cracks are observable in some of the sections.

Similar beds have now been traced from Europe by way of Arabia, the East Indies, and swinging round the continent of Australia they appear along the north coast of New Guinea, and finally in the New Hebrides.

iv. MINERAL TUFFS compare with specimens from the Wai Bubo a few hundred yards above the ford, where they overlie the Miocene limestones unconformably.

They vary in colour through shades of grey, usually dark grey. The rock is compact and hard, and is composed of fine grains of mineral matter and tiny particles of lava. In the hand-specimen it is readily distinguished from a volcanic rock by its rough fracture. Bedding planes are as a rule not well marked, though often indicated by dark streaks where magnetite grains are more numerous. Under the microscope, however, a rough differentiation of the particles into coarser and finer bands is apparent. The constituent grains are angular to subangular, and vary in size from 0.2 mm. to 0.03 mm. The constituents stated in order of abundance are:--*Plagioclase* abundant and much decomposed; *Volcanic glass* usually dusty, sometimes palagonitised; *Hornblende* light yellowish-green; *Pyroxene*, faintly coloured augite; *Magnetite* relatively exceptionally abundant. Organically derived calcium carbonate is almost entirely absent, though occasional *Globigerina* tests and, less frequently, shells of tiny gastropods have been noted, attesting to its submarine origin.

5. Perlitic hypersthene andesite glass.

Locality.—Embedded in the hypersthene andesite pumice tuffs 40 ft. above sea-level at the south-west end of Leleppa Island. In the coarse tuffs near the mouth of the cave fragments of this glass are fairly common up to 10 cm. diameter; they are usually more or less rounded, and are often faced in one or several directions as if roughly polished. On the mainland, in the neighbourhood of the Ai Stream, embedded in these tuffs were

found specimens representing a variety of stages in the devitrification of the glass to the development of a porphyritic felsite.

Macroscopic Characters.—*Colour* dark brown to black; translucent in thin splinters. *Fracture* hackly; a well developed perlitic structure causes it to break up into tiny granules a few mms. in diameter. *Texture* glassy. *Constituents* chiefly dark brown glass, in which occasionally the tiny white *felspars* are evident.

Microscopic Characters.—*Texture* hypohyaline porphyritic (vitrophyric). *Minerals present* (in approximate proportions by area):—

Glass	...	...	...	...	90%
Felspar-andesine (Ab ₅ An ₃)	...	...	...	...	6%
Hypersthene	}	...	...	...	4%
Magnetite					
Apatite					

Glass base uniformly brown and isotropic; crossed by numerous perlitic cracks. *Felspars* in clear idiomorphic crystals often 1 mm. long; generally rectangular in shape and exhibiting albite twinning with the extinction angle of andesine. Regular inclusions of a brown glass are invariably present; this characteristic is well shown in the photograph (Plate xxii., fig. 5). Corrosion by resorption is always strongly evident, and in some of the less glassy varieties of the andesite appears to have been followed by further additions to the crystal of a more basic felspar. *Hypersthene* in rods and rectangular prisms of a light green colour, up to 0.5 mm. in length: pleochroism is very faint. *Magnetite* in grains often attached to hypersthene crystals. It is developed in about equal quantities with the hypersthene. *Apatite* in long slender rods often crossing crystals of the other minerals.

Order of consolidation.—

Apatite.

Magnetite.

Hypersthene.

Felspar.

Analysis (see appended table).

N a m e.—*Hypersthene andesite perlite*.

Jevons's nomenclature.—*Vitrophyri-hyper-andesite*.

American classification :—

	NORM.				
Quartz	...	...	..	...	17·22
Orthoclase	...	...	...	...	19·46
Albite	...	..	...	...	36·15
Anorthite	...	..	...	..	14·18
Hypersthene	...	...	...	...	5·44
Magnetite	...	...	..	...	2·09
Ilmenite	...	...	..	...	1·37
Apatite	...	...	...	..	0·30
H ₂ O	..	...	...	..	4·18
					100·39

Class ii., dosalane.

Order 4, quardofelic, *Austrare*.

Rang 2, domalkalic, *Dacase*.

Subrang 3, sodipotassic, *Adamellose*.

Vitrophyri-adamellose.

A d d e n d a.—The pumiceous variety of this lava is abundantly developed in a fragmentary condition forming thick beds of tuff. In the hand-specimen it closely resembles the white drift pumice of the Pacific, which is now definitely ascertained to be derived from submarine outbursts such, for instance, as are known to have taken place within recent years along the Kermadec-Tongan fold-line. Careful estimations of silica in the Havannah Harbour pumice and in a specimen, collected by us in the New Hebrides, of white drift pumice known to have originated from a submarine eruption which took place early in 1903 in the vicinity of Tonga, gave the following results :—

Hav. Harb. pumice tuff (dried at 100° C.)	SiO ₂	...	...	...	59·68 %.
Drift pumice from vicinity of Tonga (dried at 100° C.)	SiO ₂	...	...	...	66·80 %.

Professor Liversidge has published* analyses of the two varieties of Pacific drift pumice, which are interesting for comparison.

* Journ. Proc. Roy. Soc. N. S. Wales, xx. 1886, 235.

6. Hornblende andesite.

Locality.—As a boss quite 50 yards in diameter intruding the Miocene limestones and tuffs on the Wai Malikoliko at its junction with Dry Creek.

Macroscopic Characters.—*Colour* light ash-grey. *Fracture* uneven. *Texture* fine-grained with base. *Constituents* indefinite, slightly yellowish-stained *felspars* are most numerous, but less conspicuous than tiny black prisms of *hornblende*.

Microscopic Characters (Plate xix., fig. 2)—*Texture*: Crystallinity, panidiomorphic hypohyaline. Grain-size variable, averaging 0.5 mm.

Minerals present (in approximate proportions by area):—

Glass—greyish and dusty	...	...	...	58 %
Felspar—acid labradorites (Ab_3An_2 - Ab_1An_1)	...	...	...	30 %
Hornblende—light yellowish-green	...	...	...	7 %
Pyroxene—almost colourless	...	...	...	2.5 %
Magnetite—fine grains	...	...	...	2.5 %
Apatite—a minute quantity only	...	...	...	
				100.0

Base.—The vitreous appearance of the glass is relieved by the presence of much fine dusty matter, resulting in a general yellowish-grey colour; in addition, abundant microlites and cryptoscopic fragments of the constituent minerals help to increase the turbidity.

Felspar appears in the usual idiomorphic rectangular prisms, averaging 1 mm. in length. They are much zoned, dusty areas of acid labradorite (Ab_1An_1) alternating with clearer bands of andesine (Ab_3An_2). Some of the more dusty zones closely resemble the glassy groundmass without, and it appears as if, during the growth of the crystal, envelopes of the base material had occasionally been sealed up within further additions of the crystal substance.

Hornblende appears in perfectly idiomorphic small even-sized crystals, 0.1 to 0.3 mm. diam. Multiple twinning on a plane parallel with the *a* face was observed in several cases. It is of a

light yellowish-green colour and has a narrow dark border in which magnetite dust is readily discernible. It has an extinction angle of 11° on the *b* pinacoid, and exhibits strong pleochroism.

a = light yellow,

b = greenish-yellow.

c = yellowish-green.

$a < b = c$.

Pyroxene is very scanty, appearing as tiny faintly-tinted irregular fragments whose physical properties agree closely with diopside. *Magnetite* occurs as scattered grains of small dimensions. *Apatite* is present in minute amount as tiny rods, rendered most noticeable when embedded in the substance of the felspars.

Order of consolidation—

Mag.

Apat.

Pyr.

Horn.

Fels.

Analysis (see appended table).

Name.—*Hornblende andesite*.

Jevons's nomenclature — *Panidiomorphi-hypohyal-monodiorophite*.

American classification :—

	NORM.			
Quartz ...	...	...	...	17.76
Orthoclase...	...	...	...	20.02
Albite ...	...	...	...	25.15
Anorthite ...	...	...	...	21.96
Diopside ...	...	...	...	6.45
Magnetite ...	...	...	...	5.57
Ilmenite ...	...	...	...	0.91
Apatite ...	...	...	...	0.50
CO ₂ ...	...	...	...	0.10
H ₂ O ...	...	...	...	1.21
				99.76

Class ii., dosolane.

Order 4, quardofelic, *Austrare*.

Rang 3, alkalicalcic, *Tonalase*.

Subrang 3, sodipotassic,

Hornblende-panidiomorpho-hypohyal-tonalase.

ADDENDA.—(a) Around the margin of this intrusion, and occupying numerous narrow dykes in the vicinity, is a *hornblende pyroxene andesite*, differing considerably in microscopic characters from the hornblende andesite (just described) within; there is no line of demarcation between them, the one gradually passing over into the other. In addition to the greater abundance of glassy base the following special characters of the minerals are to be noted :—The *felspars* are much less perfectly developed here, having neither the sharply defined boundaries nor attaining to such dimensions as their fellows of the interior. The *hornblende* gradually becomes more basic towards the margin, where it is a true basaltic hornblende of a clove-brown colour and deep pleochroism; this change in composition is closely followed by increasing breadth of opaque border. The *pyroxene* of the same general character as before, though in larger crystals, is now almost more abundant than the hornblende constituent.

(b) A pebble from the beach at Wuss proved to be a *hornblende andesite* nearly related to (a) above. Specially abundant in it are large *basaltic hornblendes*, with nearly straight extinction and strong pleochroism—

a = light yellow.

b = brownish-red.

c = deep red (nearly opaque).

a < < b < c.

(c) In a *hornblende pyroxene andesite* found as a pebble in the river near Bartaleppe active corrosion of the hornblende constituent is to be noted (Plate xxii., fig. 4), resulting in the production of fine grains and dust of magnetite, and a clear constituent, probably pyroxene.*

* This is the well-known alteration by magmatic resorption affecting the hornblendes of basic andesite lavas.

Examination of various types of this andesite discloses the fact that *much of the fine magnetite* which is present, darkening the base, is produced by secondary processes,* and *has resulted from the disintegration of pre-existing silicates rendered unstable by succeeding physical conditions.*

Such operations are no doubt widely experienced in the volcanic types of rocks, more especially in the basic varieties, and account for much of the second generation magnetite.

(d) In the *hornblendes of the Santo andesites*, as has already been hinted, a certain relation between thickness of altered border and basicity of the hornblende seems to prevail, whereby the more basic types have, in comparative degree, a broader peripheral zone of secondary magnetite and pyroxene.

In some cases, notably the andesite from the Wai Bubo, this alteration has continued so far that *complete magmatic paramorphism of the hornblendes* has resulted. When highly magnified, tiny rod-like microlites of augite, arranged parallel to the hornblende cleavage, can be seen amongst the magnetite dust. In the centre of one of the crystals (Plate xxiii., fig.2) is still preserved a remnant of the former mineral which, with its light yellow colour and faint pleochroism, is decidedly more acid than was expected.

7. Glomeritic Basalt Porphyrite.

Locality.—From the island of Mau, taken from the western spur at an elevation of about 600 ft.

Macroscopic Characters.—*Colour* light grey. *Fracture* uneven. *Texture* microcrystalline porphyritic. *Constituents*: the only distinguishable minerals are abundant, somewhat rounded, faintly lighter-coloured, porphyritic *plagioclases* and occasional dark-stained *olivines*.

Microscopic Characters.—*Texture*: *Crystallinity*, holocrystalline porphyritic. *Grain-size and Fabric*: two distinct crystallisations—(a) An elder generation of much larger indi-

* Subsequently it was discovered that Washington had already noted this phenomenon. Journ. Geol., iv., 273, 1896.

viduals averaging 1.5 mm. diam., porphyritically scattered through a groundmass; (b) A younger generation represented by a microcrystalline, somewhat pilotaxitic, granular groundmass.

Minerals present (in approximate proportions by area):—

	1st Gen.	2nd Gen.	Total.
Felspar ...intermed. labrad. ($Ab_1 An_1$) ...	33%	...	33
„ ...basic andesine ($Ab_3 An_2$) ...	...	26%	26
Pyroxene ...	...	24%	24
Olivine ...	1.8%	8.2%	10
Magnetite...(generations not separable) ...	...	...	7
Apatite ...(minute quantity only).			100

Felspars of the first generation are represented by labradorite ($Ab_1 An_1$) which exhibits the usual twinning, and is much marked by cleavage cracks. Inclusions are numerous and show a decided inclination to elongation in the direction of the prism zone; brown glass, pyroxene, magnetite grains, serpentinous-looking matter, and, less often, liquid enclosures are to be noted. The crystals are typically developed in aggregates averaging 2 mm. diam., in which the individuals are bunched in an obscure radial fashion. This is a variety of the glomero-porphyritic structure described by Prof. Judd;* this case is distinguished by the fact that the aggregates are composed of felspars only. A typical felspar glomerule† is shown in the photograph (Pl.xxiii. fig.4); in it the clear area within the zone darkened by increased abundance of inclusions is an assemblage of first generation labradorite crystals, whose multiplicity is rendered evident under crossed nicols (Pl.xxiii. fig.5). These felspar glomerations were no doubt developed, freely suspended, at a time preceding the final ascent of the lava; this crisis is indicated by the narrow peripheral zone in which, owing to very rapid crystallisation,‡ inclusions are extremely abundant. Outside this latter dark zone, there appears a narrow marginal band of clear glassy felspar

* Q.J.G.S. xlii. 71, 1886.

† Glomerule is a botanical term, but can be equally well applied to such mineral agglomerations.

‡ Under high power magnification the labradorites show up with a rounded and somewhat ragged outer border, suggesting that possibly corrosion was the cause of the darkened zone.

which proves to be a rather basic andesine ($Ab_3 An_2$), the same with that of the second generation; this addition has been made during the second generation of crystallisation, and is in crystalline continuity with the labradorites of the kernel; the felspar glomerules show, therefore, the phenomenon of rejuvenescence.

Pyroxene is represented only in the groundmass, where it appears in quantity as light greenish-yellow grains. *Olivine* in large clear porphyritic crystals up to 2 mm. diam.; also in the groundmass as microscopic idiomorphic grains. *Magnetite* appears in scattered grains, usually very tiny. *Apatite* in tiny laths, one of the first products of crystallisation.

Order of consolidation---

Fels.		Mag.		Mag.		Oliv.		Pyr.		Fels.
		Mag.								
			Oliv.							

Analysis (see appended table).

Name.—*Glomeritic basalt porphyrite*.*

Jevons's nomenclature.—*Glomerophyri-pilotaxi-oli-fels†-gabbromicrite*.‡

American classification:—

					NORM.
Quartz	...	...	...	...	4.20
Orthoclase	...	...	...	...	3.34
Albite...	...	...	...	...	12.05
Anorthite	...	...	...	...	49.76
Diopside	...	...	...	...	6.31
Hypersthene	...	...	...	...	13.19
Magnetite	...	...	...	...	6.37
Ilmenite	..	...	...	...	2.28
Apatite	...	...	...	...	0.90
H ₂ O	...	...	...	...	1.44
					100.20

* The term *basalt porphyrite* seems to be particularly applicable to a rock of this type—a basalt containing a generation of coarsely crystalline matter more abundant than the expression *porphyritic basalt* signifies.

† Although felspar is here an index mineral, yet its exceptional abundance warrants special mention.

‡ No definite knowledge of the dimensions of the mass were obtained; all that can be said with certainty is that it is an intrusion.

Class ii., dosalane.

Order 5, perfelic, *Germanare*.

Rang 4, docalcic, *Hessase*.

Subrang 3, presodic, *Hessose*.

Oli-salglomerophyro-pilotaxiti-hessose.

8. Olivine Basalt Porphyrite.

Locality.—From the numerous dykes and sills intruding the agglomerates in the vicinity of Fatmalapa, Efaté.

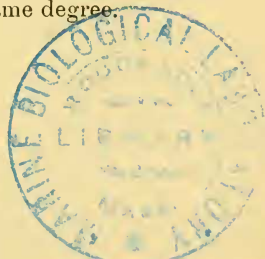
Macroscopic Characters.—*Colour* dark grey with scattered reddish-stained phenocrysts. *Fracture* fairly even with a rough surface. *Texture* microcrystalline porphyritic. *Constituents*: porphyritic *olivines* stained reddish by iron oxide are very noticeable. Less frequent are large *pyroxenes* which appear darker than the fine-grained base.

Microscopic Characters.—*Texture*: *Crystallinity*, holocrystalline porphyritic. *Grain-size*: two distinct crystallisations: (a) An elder generation of scattered individuals averaging 1 mm. diam.; (b) A younger generation represented by the microcrystalline pilotaxitic groundmass, equal to 65 % of the rock by area.

Minerals present (in approximate proportions by area):—

	1st Gen.	2nd Gen.	Total.
Felspar—labradorite (Ab_2An_3)	30%	28%	58%
Pyroxene—light yellow augite	3%	27%	30%
Magnetite	2%	4%	6%
Olivine	4%		4%
Apatite and decomposition products			2%

Felspar of both generations is labradorite (Ab_2An_3), in crystals more or less rectangular in habit and exhibiting the usual cleavage. The earlier crystallisations average about 2mm. diam., and though usually single, the crystals are often aggregated into small bunches containing several; these are the felspar glomerules noted in the Mau basalt. In this rock, however, the glomerules are distinct in that they are neither so well developed nor do they show evidence of rejuvenescence in the same degree.



Large inclusions, chiefly of glassy materials, are a feature of these bigger individuals. The second generation is represented by the microcrystalline reticulated laths of the groundmass and, only to a very limited extent, as a marginal zone around the earlier crystallisations, from which it is distinguished by its less basicity. *Pyroxene* is a light yellow augite developed chiefly as tiny grains (microgranulitic) in the interstices of the felspar laths of the base. Large idiomorphic crystals up to 2 mm. diam. are present only to the extent of about 3 %. *Olivine* phenocrysts up to 3 mm. diam. are a prominent feature even in the hand-specimen, not only on account of their size, but for the fact that they are stained reddish along the cracks by deposition of iron oxide. The clear olivine itself has a slightly pinkish appearance, probably indicating a high iron percentage. *Magnetite* is present in grains derived from both crystallisations.* It is represented in the former to the extent of about 2 % by individuals up to 0.5 mm. diam.; in the base it appears as tiny particles scattered about indiscriminately. *Apatite* in microscopic needles is present adhering in radial fashion to the tiny magnetite grains of the groundmass. A little apatite is included in the first generation individuals. *Secondary minerals*: Serpentine and other fine fibrous secondary minerals of a greenish colour, are developed to a slight extent, filling up small crevices.

Order of consolidation—

Fels.				Mag.			
	Mag.				Apat.		
		Oliv.				Pyr.	
			Pyr.				Fels.

A n a l y s i s (see appended table).

N a m e.—*Olivine basalt porphyrite.*

Jevons's nomenclature.—*phyri-pilotaxi-oli-gabbromicrite.*

* In such a rock as this it is quite uncertain how much of the magnetite is primary and how much has been developed by later crystallisations and recrystallising processes.

American classification :—

	NORM.				
Orthoclase	...	...	...	...	3·34
Albite...	...	...	...	...	11·53
Anorthite	...	...	...	...	40·59
Diopside	...	...	...	...	11·74
Hypersthene	...	..	..	...	15·97
Olivine	...	...	...	...	2·31
Magnetite	...	...	...	...	8·82
Ilmenite	...	...	...	...	2·28
Apatite	...	...	...	...	0·62
H ₂ O	...	...	...	...	2·72
					99·92

Class iii., saffemane.

Order 5, perfelic, *Gallare*.

Rang 4, docalcic, *Auvergnase*.

Subrang 3, presodic, *Auvergnose*.

Salfemphyro-pilotaxiti-auvergnose.

Addenda.—This rock has been derived from the same magma as has the Mau basalt, the difference lying in that it is the habitant of narrower intrusions, which has had the effect of breaking up the large glomerules. In character it is slightly more basic and shows evidence of more rapid crystallisation. Where there is an intrusive contact with the coralliferous limestone of the older terraces, a marginal zone about one foot wide appears, which, owing to the presence of very numerous white particles, presents a speckled appearance. Under the microscope these white particles are found to be irregular fragments of the limestone, averaging 1 mm. diameter; very little resorption is evidenced, and no new minerals have been developed, though the limestone has lost all trace of organic structure and has assumed the characters of marble.

9. Uralite Porphyry.

Locality.—Specimens were collected on Malekula as rolled pebbles in the bed of the river entering the sea just to the north of Atchin. The material represents various stages in the metachemisation.

Macroscopic Characters.—A dark grey compact rock with porphyritic texture and uneven fracture. Large porphyritic *uralites* with greenish sheen are very noticeable constituents; much less common are whitish areas of *saussuritised felspar*. *Pyrites* is present in strings and grains in notable amount.

Microscopic Characters (Pl. xxiii., fig.3)—*Texture* hypocrystalline porphyritic. *Composition*: evidently a very much altered pyroxene porphyry, but retaining little of its former appearance.

The *groundmass*, which composes quite 60% of the rock, is almost opaque, owing to the large amount of fine magnetite scattered through it; tiny plagioclase laths of microlitic dimensions are, however, discernible to some extent. There are three notable porphyritic constituents:—*Felspar* in rectangular crystals about 1 mm. in length and still retaining traces of albite twinning, though now completely converted to *saussurite*; traces of original inclusions are still retained, though now almost without exception converted to some form of *actinolite*. *Uralite* in beautiful crystals up to 5 mm. diam. retaining the perfect idiomorphic form of the original pyroxene. Sections parallel to the vertical axis are always strongly striated (Pl. xxiii., fig.3). Some of the sections prepared show crystals in which an outer zone of uralite appears enveloping a central area still occupied by the original pyroxene (Pl. xxii., fig 3). The pyroxene is perfectly colourless, has a low extinction angle, and in the basal section shows three cleavages; it is therefore related to diallage. The amphibole has an extinction angle of 12° , appears light yellowish-green in section, and is strongly pleochroic:

a = faint yellow.

b = olive green.

c = grass green.

$a < b = c$.

It therefore closely resembles actinolite, and is the variety termed *Smaragdite*. The *third notable constituent* is an alteration product of some mineral whose identity is yet doubtful. It

appears usually irregular in outline and seldom exceeding 1 mm. diam.; in two cases the form was such as to suggest hornblende* as the original mineral—see photograph of one of these (Pl. xxiii., fig.1). The most noticeable of the minerals composing these aggregates is *actinolite*, in perfectly idiomorphic yellowish-green rods crossing and recrossing each other indiscriminately. It has an extinction angle of 20° , and the following pleochroism—

a = light yellow.

b = grass-green.

c = light bluish-green.

a < b > c.

Between these actinolite laths is a base of tiny granular clear *felspar*. A zone of *magnetite* grains is often present, forming a dark ring towards the centre of the section (Pl. xxiii., fig.3). *Zoisite* in small quantity is sometimes present near the periphery.

A d d e n d a . — Another pebble fragment collected in the same locality evidently represents a further stage in the alteration of this rock. In it the original structure has almost entirely disappeared, and the minerals present are all of secondary origin. *Zoisite* and various forms of actinolite are the chief constituents. The *zoisite* and *epidote* in very tiny particles form considerable areas, which appear as a mosaic under crossed nicols. The *actinolite* is fibrous, arranged in radiating and sheaf-like aggregates without sharply defined borders. *Pyrites* is comparatively abundant, scattered indiscriminately through the section. Some of the lighter areas appear to represent the sites of former felspar crystals, which have passed through the various stages of saussuritisation, and are now represented by a mosaic of colourless to faintly grey *zoisite*, in which are scattered aggregates of actinolite-like amphibole and, occasionally, *epidote* in recognisable grains. In the less metamorphosed varieties of the rock these actinolite aggregates are seen to be developed from inclusions

* Others, again, are so irregular in form that it is thought more than probable that they are the sites of original cell-spaces.

which are chiefly glassy. Phenocrysts of *smaragdite* are still discernible, though their sharp outline has been lost.

TABLE OF ANALYSES.

	i.	ii.	iii.	iv.
SiO ₂	63.60	46.78	43.98	60.96
Al ₂ O ₃	15.84	21.22	17.69	16.62
Fe ₂ O ₃	1.45	4.63	5.97	3.87
FeO	2.72	6.17	6.68	2.61
MgO	1.14	4.30	7.83	0.95
CaO	3.03	12.07	11.71	6.35
Na ₂ O	4.33	1.40	1.34	3.01
K ₂ O	3.26	0.64	0.64	3.40
H ₂ O+	3.88	0.94	1.77	1.03
H ₂ O-	0.30	0.50	0.95	0.18
CO ₂	nil	trace	trace	0.10
TiO ₂	0.70	1.20	1.20	0.50
P ₂ O ₅	0.10	0.31	0.32	0.25
Cr ₂ O ₃	trace	0.05	0.05	0.04
MnO*	inconsiderable	inconsiderable	inconsiderable	inconsiderable
SrO	nil	nil	nil	nil
BaO	nil	nil	nil	nil
Li ₂ O	nil	nil	nil	nil
S	faint trace	nil	nil	trace
Cl	faint trace	faint trace	faint trace	faint trace
Σ	100.35	100.21	100.13	99.87
Sp.Gr.	2.51	2.90	2.95	2.54

INDEX.

- i. Hypersthene andesite perlite; Leleppa Island.
- ii. Basalt porphyrite (with felspar glomerules); Island of Mau.
- iii. Basalt porphyrite, the dyke equivalent to No.ii.; from dykes and sills intersecting the agglomerates in the vicinity of Fatmalapa on the mainland of Efaté.
- iv. Hornblende andesite; Wai Malikoliko, S. W. Santo.

SUMMARY.

The chain of islands forming the New Hebrides group, owes its existence, primarily, to the development during Miocene times of a fold-ridge, apparently continuous with that passing around the

* The colour of the fused cake was in all cases very faint, indicating probably not more than 0.15% MnO; in order to save time, this was precipitated with the Fe₂O₃.

north of New Guinea, through Sumatra, and on to the better known region of the Himalayas and Southern Europe. In the New Hebrides, the folding period was preceded by local shallow marine conditions and subdued volcanic activity. The folding force would appear to have been exerted from the direction of Fiji, against the foreland of New Caledonian crystalline schists and gneisses; a single ridge probably resulted, defining the western line of islands where extensive outcrops of Miocene strata are exposed—in Santo, Malekula and possibly Efaté.

In accordance with Professor Suess's observations, subsidence of the outer wing has, judging by the evidence of the Wai Bubo beds, been overthrust, allowing of the intrusion of andesite lavas followed by extensive late Miocene andesitic eruptions along the plane of weakness. The result of the accumulation of volcanic products from these eruptions along the ridge has been to accentuate its features, so that, at the present day, a drop of almost 22,000 feet is experienced within 50 miles (see Plate xxvi.).

The next epoch-making feature in the development of the New Hebrides was probably a faulting of the inner wing of the fold along the line of present active volcanoes, letting down the sea floor to the east, thus putting fairly deep water between the New Hebrides and the Fiji land-surface. Along this fracture even larger volcanoes than ever were developed, extruding not andesite lavas but basalts. These eruptions commenced probably about middle Pliocene and extended down to recent times.

During all this period of volcanic activity, extensive submarine tuffaceous beds were accumulating above the folded Miocene series; the earlier deposits of the nature of the Wai Bubo mineral tuffs, followed later by varieties of soapstone. No interbedded coral limestone was met amongst these tuffs, though occasional beds proved to be highly calcareous, due to the presence of abundant remains of the smaller foraminifera.

Capping this series, are the raised coral reefs elevated to heights of over 2000 feet. The oldest of these is referable to a period not earlier than late Pliocene and probably not much later, as it has since been intruded by lavas from centres now

extinct. The limestone forming the series of more recent raised reefs is considerably newer in appearance, and so is probably to be relegated to a very recent epoch.

The elevatory movements evidenced in these raised reefs is of a see-saw type, greatest in the west, and least (probably in many cases a minus quantity) in the east, where the great recent basic eruptions have taken place. As these eruptions were contemporaneous with the upheaval it might be argued that they were the prime cause of the disturbance; this, however, can hardly be the case, as the tilt is down towards the centres of eruption, where it is usually negative.

The proportionate increase in relative heights of the terraces in an east to west traverse is proof that the upheavals were not primarily horizontal, and the present easterly dip produced later by the development of a sag in towards the volcanic centres.

From these facts it seems most reasonable to relate the elevatory tendency to a continuance* of the tectonic movements so critically developed in Miocene times, and to regard the volcanic eruptions as a direct outcome of the folding and consequent on it. It is, however, still maintained that minor elevations may have been directly due to the volcanoes, as evidenced by the fairly numerous intrusions of andesite into the Miocene series.

If at any time the New Hebrides ridge formed continuous land connected in the north or elsewhere with other land-masses, these conditions are most likely to have prevailed in its early history. Geological evidence, so far as ascertained, is in this respect uncertain, but that such must have been the case has been conclusively proved on biological grounds by evidence brought forward by Mr. C. Hedley.†

* The Himalayas afford a classical example of continuance of folding, beginning in the Eocene and extending down to recent times. *Vide* Suess, 'The face of the Earth.'

† "A Zoogeographic Scheme for the Mid-Pacific." *Proc. Linn. Soc. N. S. Wales*, xxiv. 391, 1899.

Extensive trough-faulting crossing the original fold almost perpendicularly* and resulting in the development of an island chain, most probably, therefore, did not follow directly on the formation of the primary fold, but succeeded it after the lapse of a longer or shorter period,† giving time for the migration of representatives of the Papuan fauna as advocated by Mr. C. Hedley.

Comparing New Hebridean tectonic geology, as developed in this paper, with that of Sumatra, a continuation of the same fold chain, the perfect similarity will be at once apparent. As no beds older than the Miocene‡ were met with in the Group, the nature of such developed at a depth is entirely problematical; since, however, later geological features in these two regions have so much in common, it is probable that the similarity extends back to the older formations, and we should then expect to find below the New Hebrides Miocene an extensive development of serpentine and diabase. The probability of such being the case is greatly strengthened by the fact that in New Caledonia, not far distant, and in New Zealand, to the south, a continuation of the same fold-chain, the serpentine horizon is strongly developed.

CONCLUSIONS.

The discovery that the New Hebrides Islands are a fold-chain of Alpine age throws great light upon our knowledge of South Pacific geology, and at once suggests the application of similar principles with regard to other island groups.

Accordingly, after a careful study of the Admiralty charts and an elementary knowledge of the geology of the islands, it will be

* Lines of weakness crossing the fold would, in all probability, be produced contemporaneously with its formation in accordance with the blätter type of faulting; actual trough subsidences though would be precipitated by the later extravasations of lava.

† So far as our observations went, such was found to be the case, *e.g.*, the Tasiriki fault crossing the recent raised coral, and the Havannah Harbour fault crossing the soapstone.

‡ It is none the less probable that limited outcrops do occur, as from the advanced metamorphic state of the pebbles of uralite porphyry from Malekula they must date back to times preceding the folding.

at once conceded that the South Pacific Island Groups are lined along great fold-chains concentric on the Australian archibole. Discontinuity of the land-areas is due to a variety of local causes, two of which figure most prominently; in the first place, inevitable cross-faulting of the blätter type, succeeded by its attendant after-result cross trough-faulting; secondly, the fact that many of the ridges would probably not be sufficiently elevated, to rise above sea-level, the present isolated land-areas chained along the crests, resulting from subsequent continued accumulation of volcanic products, derived from eruptive centres developed along the septa.

The direction of folding has probably been defined by the trend of parallel fold-ridges of Hercynian age, which can be traced, one following closely the contour of the east coast of Australia; another seems to pass down the Owen Stanley Ranges of New Guinea,* through New Caledonia,† to meet the great Carboniferous fold of the Southern Alps of New Zealand, which latter, pointing as it does, seems to indicate a continuation to the northward in the direction of Samoa, or more probably, now that we know of the existence in Viti Levu‡ of older rocks, through Fiji. It is this Hercynian folding which, by isolation§ from Australia, gave birth to Mr. Hedley's Mid-Pacific Continent. The similarity of the Mesozoic fossils|| in New Caledonia and New Zealand, shows that the land-area in this direction must have

* Annual Report on British New Guinea. Parliamentary Papers, Brisbane, 1893. Also "The Salient Geological Features of British New Guinea." By A. Gibb Maitland, Journ. West Aust. Nat. Hist. Soc. No.ii. May, 1905.

† Piroutet, M., "Preliminary Note on the Geology of a Part of New Caledonia." Bull. Soc. Géol. France, iii. 156, 1903.

‡ Woolnough, W. G., "The Continental Origin of Fiji." Proc. Linn. Soc. N. S. Wales, xxviii. 457, 1903.

§ As shown by the similarity among the fossils in these two regions in times preceding the later Carboniferous, and dissimilarity in succeeding periods.

|| The Rev. W. B. Clarke was the first to draw attention to this, from which he argued an extensive land-area connecting both these localities, "Plain Statements," 1851, p.6.

been considerable and permanent during that period. It is probable though that, in the early Tertiaries, with the development of further folding, the land began to break up,* until, as now, so little of the original remains. Evidence available in New Caledonia and New Zealand dates the commencement of this folding to a period subsequent to the Cretaceous, whilst unconformities in the later rocks of the New Hebrides are proof of its continuance down to the present time. Extreme upheaval, which in Santo and Malekula has laid bare a continuous series, from horizontally bedded recent raised reef débris above, to a basis of folded Miocene below, allows of a critical enquiry into the nature of the movements which have contributed to the present topography. Analysing this evidence, it would seem that earlier features in the development were of the nature of true folding, but that later tendencies had been towards almost horizontal uplifts, resulting in a maximum elevation above sea-level of perhaps 4000 feet.†

Extended observation in South Pacific tectonics seems to show that a similar cycle of operations has been most widely exercised. The interesting result is therefore arrived at that *more or less horizontal positive and negative movements are often a feature of the later phases in mountain-building.*

Situated as this region is in a tropical climate, these slow, progressive, and fairly regular movements have been faithfully and indelibly recorded by the industrious coral polyp, whose mode of life has resulted in the development of three main types of islands, from as many possible land-movements.

* Just as the East Indian Continent is known to have "gradually and irregularly broken up," Wallace, A. R., "On the Physical Geography of the Malay Archipelago." Journ. Geogr. Soc. xxxiii. 233, 1863.

† See Part i. Sec. 1. Santo. The fact that some mountain-ridges owe their elevated position to nearly horizontal uplifts through considerable heights has been clearly demonstrated by Prof. W. M. Davis, "The bearing of Physiography upon Suess' Theories," xix. 265, 1905. Also by the same author, "The Geographical Cycle in an arid Climate," Journ. Geol. 1905, p. 381.

Firstly, in regions of *continuous upheaval*, islands are veneered with coralliferous limestone terraces, *e.g.*, The New Hebrides.

Secondly, islands situated on *subsiding areas* are typically atolls, *e.g.*, The Ellice Group.*

The third type of island, is one in which coralliferous limestone is found interbedded with submarine tuffs or other material, being evidence *both of upheaval and subsidence*; such areas are, as a rule, larger land-masses, *e.g.*, Viti Levu,† and have been affected by oscillatory movements of the earth's crust, and not by folding of the acute type defining most of the South Sea Island ridges.

The most promising field for future work, extending these observations on Pacific tectology, is undoubtedly South-Eastern, New Guinea and the neighbouring islands, where it is hoped that shortly further investigations may be prosecuted.

The author wishes to express his great indebtedness to Capt. E. G. Rason, R.N., British Resident Deputy Commissioner in the Group, for help afforded and considerable trouble taken to ensure as thorough an examination of the Group as circumstances would permit of.

To Professor T. W. E. David, B.A., F.G.S., F.R.S., we have been in a chronic state of indebtedness for much assistance rendered ever since his first suggestion of the undertaking.

Our thanks are also due to the following gentlemen:—Commander J. P. Rolleston of H.M.S. "Archer" for cordial assistance in extending our field operations; Professor A. Liversidge, M.A., LL.D., F.R.S., and Acting Professor J. A. Schofield, A.R.S.M., F.C.S., for facilities offered the conduct of the research;‡ Messrs. W. S. Dun and C. Hedley, F.L.S., for advice in publication.

* "The Atoll of Funafuti," Lond. 1904.

† Woolnough, W. G., "The Continental Origin of Fiji," Plate xxii., fig. 1.

‡ The several rock-analyses undertaken were conducted in the chemical laboratory during the author's term of Junior Demonstratorship.

APPENDIX.

List of fossil forms identified at the Australian Museum, and occurring in the New Hebrides, in rocks ranging from Pliocene to Recent.

DETERMINATIONS OF MOLLUSCA.

By MR. C. HEDLEY, F.L.S., CONCHOLOGIST.

"After spending considerable time on Mr. Mawson's collection, I return it with such identifications of shells as I was able to make. It contains a number of species which are probably new to science, but the task of elaborating these for publication would be both lengthy and laborious. Viewed as recent species, the material is not well enough preserved for description. The collection represents material from a deeper zone than the beach. As no dredging has been done in this archipelago, nothing is known of the deep-water fauna, with which this collection ought to be compared. The lot numbered 165 [Tasiriki foundation-beds] reminds me of the mollusca I dredged in 15 fathoms off the Palm Islands. In lot 242 [Foreland fossiliferous cinder-beds] the appearance of *Cucullæa*, *Conus*, *Pleurotoma*, and *Cardium* suggests a like origin."

Brachiopoda.

1. *Thecidia maxilla* Hedley.

Pelecypoda.

- | | |
|------------------------------------|--|
| 1. <i>Arca</i> sp. | 12. <i>Dosinia</i> sp. |
| 2. <i>A. antiquata</i> Linn. | 13. <i>D.</i> sp. |
| 3. <i>A. clathrata</i> Rv. | 14. <i>Hippopus hippopus</i> Linn. |
| 4. <i>A. lima</i> Rv. | 15. <i>Leda</i> sp. |
| 5. <i>Amusium</i> sp. | 16. <i>Lima</i> , sp. nov. |
| 6. <i>Cardium</i> sp. | 17. <i>L.</i> sp. (? <i>L. alata</i> Hedley). |
| 7. <i>C. bechei</i> Rv. | 18. <i>Limopsis</i> sp. |
| 8. <i>Cardita</i> sp. | 19. <i>Lithophaga</i> sp. (? <i>L. levigata</i> Q. & G.) |
| 9. <i>Chlamys</i> sp. | 20. <i>Lucina</i> sp. |
| 10. <i>Circe gibba</i> Lam. | 21. <i>Pecten</i> sp. |
| 11. <i>Cucullæa camerata</i> Brug. | |

- | | |
|------------------------------------|---------------------------------|
| 22. <i>P. pallium</i> Linn. | 27. <i>Tellina</i> sp. |
| 23. <i>Pectunculus</i> sp. | 28. <i>Theora</i> sp. |
| 24. <i>Puncturella</i> sp. | 29. <i>Thracia</i> sp. |
| 25. <i>Spondylus varians</i> Sowb. | 30. <i>Tridacna gigas</i> Linn. |
| 26. <i>Tapes</i> sp. | |

Scaphopoda.

- | | |
|-------------------------|--------------------------------------|
| 1. <i>Cadulus</i> sp. | 3. <i>D. quadricostatum</i> Brazier. |
| 2. <i>Dentalium</i> sp. | |

Gastropoda.

- | | |
|------------------------------------|-------------------------------------|
| 1. <i>Acmea</i> sp. | 23. <i>Olivella</i> sp. |
| 2. <i>Acteon</i> sp. | 24. <i>Oliva irisans</i> Lam. |
| 3. <i>Atlanta</i> sp. | 25. <i>Pleurotoma</i> sp. |
| 4. <i>Bittium</i> sp. | 26. <i>P. crispa</i> Lam. |
| 5. <i>Cassis vibex</i> Linn. | 27. <i>Pyrgulina</i> sp. |
| 6. <i>Columbella</i> . | 28. <i>Retusa</i> sp. |
| 7. <i>Conus</i> sp. | 29. <i>R. pyriformis</i> A. Ad. |
| 8. <i>C. gubernator</i> Hwass. | 30. <i>Ringicula</i> sp. |
| 9. <i>C. lividus</i> Hwass. | 31. <i>Scala</i> sp. |
| 10. <i>Cylichna</i> sp. | 32. <i>Seguenzia</i> , sp. nov. |
| 11. <i>Eulima</i> sp. | 33. <i>Solarium</i> sp. |
| 12. <i>Gyrineum pusillum</i> Brod. | 34. <i>Strombus urceus</i> Linn. |
| 13. <i>Liotia</i> sp. | 35. <i>S. ustulatus</i> Schumacher. |
| 14. <i>Mitra</i> sp. | 36. <i>Syrnola</i> sp. |
| 15. <i>M. coronata</i> Lam. | 37. <i>Teinostoma</i> sp. |
| 16. <i>Murex ternispina</i> Lam. | 38. <i>Terebra dimidiata</i> Linn. |
| 17. <i>Nassa</i> sp. | 39. <i>T. subula</i> Linn. |
| 18. <i>Natica</i> sp. | 40. <i>Triphora</i> sp. |
| 19. <i>N. areolata</i> Recluz. | 41. <i>Trochus maculatus</i> Linn. |
| 20. <i>Nerita maxima</i> Gmelin. | 42. <i>Turbonilla</i> sp. |
| 21. <i>N. undulata</i> Linn. | 43. <i>Turritella</i> sp. |
| 22. <i>Odostomia</i> sp. | |

Pteropoda.

- | | |
|-----------------------------------|--------------------------------------|
| 1. <i>Cavolinia inflexa</i> Less. | 4. <i>Clio pyramidata</i> Linn. |
| 2. <i>C. longirostris</i> Less. | 5. <i>C. subulata</i> Q. & G. |
| 3. <i>C.</i> sp. | 6. <i>Cuvierina columnella</i> Rang. |

DETERMINATIONS OF ALGÆ, &c.

BY MR. T. WHITELEGGE, F.R.M.S., ZOOLOGIST.

Algæ.

1. *Halimeda opuntia* Ellis & Solander.

Polyzoa.

1. *Retepora*.

Hydrocorallinæ.

1. *Distichopora* sp.

Corallinæ.

- | | |
|------------------------------------|---|
| 1. <i>Astræa</i> sp. | 11. <i>Herpolitha</i> (?). |
| 2. <i>Cœloria</i> . | 12. <i>Leptastræa</i> . |
| 3. <i>Conocyathus</i> sp. | 13. <i>Leptoria</i> sp. |
| 4. <i>Cyphastræa</i> sp. | 14. <i>Madrepora</i> sp. |
| 5. <i>Echinopora reflexa</i> Dana. | 15. <i>Mussa</i> sp. |
| 6. <i>Fungia</i> . | 16. <i>Orbicella</i> sp. |
| 7. <i>Galaxea</i> sp. | 17. <i>Pavonia</i> (?) sp. |
| 8. <i>Goniastrea</i> sp. | 18. <i>Porites</i> sp. |
| 9. <i>G.</i> sp. | 19. <i>Stylophora palmata</i> (?) Blainv. |
| 10. <i>Heliopora</i> (?). | |

Echinoidea.

- | | |
|--|-------------------------------------|
| 1. <i>Brissus carinatus</i> Lam. | 3. <i>Echinocyamus</i> sp. |
| 2. <i>Clypeaster scutiformis</i> Gmel. | 4. <i>Laganum depressum</i> Lesson. |

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EXPLANATION OF PLATES XIV.-XXIX.

Plate xiv.

View of the hills (highest point, Mt. Macdonald, 2263 ft.) to the south of Undine Bay, Efaté; taken from near the north-west corner of Pelé. Note the various raised reefs and their respective dips. The foundation-rock, a basic agglomerate traversed by numerous dykes and sills, is largely exposed at the higher levels; above, forming a capping, distinctly outlined in the photograph, is a further raised reef-horizon.

Plate xv.

View of the volcanic Island of Mau, taken from the north-east coast of Pelé. The rock in the foreground is a recent coral limestone very much darkened, owing to the quantity of basic lava fragments bound up in it. Such fragments are washed or rolled down from the steep cliffs behind, and carried out into the growing reef. The surf-line marks the edge of the fringing reef; the large black rocks supported on it nearer inshore are rolled masses of basalt.

Plate xvi.

Fig. 1.—Nguna Island, taken from Scott's Plantation, Efaté. The island is here seen to be formed of a line of craters, three of which are visible in the photograph. The one furthest to the left is Tavanaki (2013 ft.), from the top of which several photos were subsequently taken.

Fig. 2.—View of the islands to the north, taken from the summit of Nguna (Tavanaki). The islands in view, reading from the left, are:—MAI, distant 25 miles; MAKURA, 20 miles; MATOSO (two hills joined by a low spit), 12 miles; MONUMENT ROCK OR WOT (an isolated rock standing to the right in the photograph), 12 miles. The three islands in the back row are:—TANGOA (behind the eastern extremity of Matosa), 35 miles; BUNINGA (next in order) 30 miles; TONGARIKI (on the extreme right behind Wot), 31 miles.

Plate xvii.

The west coast of Santo taken from Tasiriki, looking north. To the right, the recent coral formations appear, contrasting strongly with the precipitous bluffs of Miocene rocks at Cape Babana in the distance.

Plate xviii.

Taken from Tangoa, looking towards Losubunu (Santo Peak, 5520 ft.), distant 16 miles; showing the disposition of the Miocene Ranges. A horizontal sky-line in the vicinity of Losubunu, terminating to the south of Talapone, probably indicates a former sea-level now elevated over 4000 ft.

Plate xix.

The highly-tilted Miocene limestones (dip 55° S., 17° W.) of the Wai Bubo, Santo.

Plate xx.

Cape Ukuani from the south, Santo. The rock in the foreground is recent raised coral limestone. Outcropping at the base of the headland, and at increasingly higher elevations inland, are massive agglomerates which pass upwards into well-bedded soapstone-like foundation-beds, a good face of which can be seen on the photo amongst the trees; a coral limestone capping is developed in the right hand top corner, but is hidden from view by the dense foliage.

Plate xxi.

The hill Tumebu and vicinity as seen from Tangoa, South Santo. Tumebu, an outlier, so to speak, of the terraces behind, is a typical raised coral hill.

Plate xxii.

Fig. 1.—View taken from M. Chevillard's plantation overlooking Vila Harbour and Meli Bay, and showing a wonderful raised coral plateau (almost blending with the sky) in the distance eight miles away.

Fig. 2.—Hornblende andesite of Wai Malikoliko; magnified 23 diams.; for description, see p. 459.

Fig. 3.—A crystal of uralite still retaining a kernel of the original pyroxene; magnified 30 diams.; surrounding the lighter pyroxene is fibrous smaragdite. From the uralite porphyry of Malekula; for description, see p. 468.

Fig. 4.—Corroded hornblende crystal out of basic hornblende pyroxene andesite from North Malekula; magnified 27 diams.; for description, see p. 461.

Fig. 5.—A typical felspar crystal in the felsophytic hypersthene andesite of Havannah Harbour; magnified 24 diams. Shows glass inclusions arranged in curtain-structure. The white patches in the ground-mass are cellular cavities; for description, see p. 457.

Plate xxiii.

Fig. 1.—Pseudomorph in actinolite (dark lath-shaped crystals) and felspar, etc., after a mineral (species uncertain) in the uralite porphyry from Malekula; magnified 47 diams.; for description, see p. 469.

Fig.2.—Hornblende crystal paramorph in magnetite dust and augite micro-lites, from the Wai Bubo andesite; magnified 23 diams. The light central area is part of the original amphibole; for description, see p.462.

Fig.3.—Uralite porphyry from North Malekula; magnified 23 diams. The large crystals are uralite in a dense groundmass. To the left of the section a small crystal with a triangular zone of magnetite is a diametral section through an aggregate similar to that shown in Fig.1; for description, see p.468.

Fig.4.—A felspar glomerule in the Mau basalt; magnified 24 diams. Note the central labradorite, peripheral zone darkened by inclusions, and marginal andesine; for description, see p.463.

Fig.5.—The same aggregate under crossed nicols showing the multiple character; magnified 24 diams.

Plate xxiv.

Section along Steep Gully, Havannah Harbour; showing the character of the terraced limestone veneer and of the andesite foundation-tuffs.

Plate xxv.

Sketch section, slightly generalised, from Cape Tsinone to Losubunu (the highest point in the New Hebrides), South-west Santo; showing the folded Miocene tuffaceous limestones intruded by andesite lavas. At the north-east end of the Section, the site of an old Miocene volcano, the lava-series appears to be quite 5000 feet thick. Toward the left hand side, a small outcrop of the Miocene series, dipping steeply to the S.W., represents the overfolded beds exposed on the Wai Bubo.

Plate xxvi.

Generalised Section across the New Hebrides chain. A typical section of the primary Miocene fold-chain is shown in Santo on the left. Note the overfolding of the Miocene series, and extrusion of andesite lavas. Ambrym, one of the islands of the eastern wing, is a great recent volcano, situated probably along an inner wing-fault which has let down the sea-floor considerably between the New Hebrides and Fiji.

Plate xxvii.

Map of New Hebrides Group taken from Admiralty charts. Note the east and west wings typified by basic and andesitic lavas respectively; at Efaté the two wings junction, and both series of lavas are found in juxtaposition; further south, after crossing the western land-ridge, the line of basic cones alone remains visible.



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